Annexes

The following seventeen annexes provide additional information to the material presented in the main body of this report. Annexes A through I discuss methodologies for individual source categories in greater detail than was presented in the main body of the report and include explicit activity data and emission factor tables. Annex J presents a technical summary on the derivation of Global Warming Potential values and some of the uncertainties related to their use to weight greenhouse emission estimates. Annexes K and L summarize U.S. emissions of ozone depleting substances (e.g., CFCs and HCFCs) and sulfur dioxide (SO_2), respectively. Annex M provides a complete list of emission sources assessed in this report. Annexes N and O present U.S. greenhouse gas emission estimates in the reporting format recommended in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC/UNEP/OECD/IEA 1997) and the IPCC reference approach for estimating CO_2 emissions from fossil fuel combustion, respectively. Annex P addresses the criteria for the inclusion of an emission source category and some of the sources which meet the criteria but are nonetheless excluded from U.S. estimates. Annex Q provides some useful constants, unit definitions, and conversions. Annexes R and S provides a listing of abbreviations and chemical symbols used. Finally, Annex U contains a glossary of terms related to greenhouse gas emissions and inventories.

List of Annexes

Annex A

Methodology for Estimating Emissions of CO_2 from Fossil Fuel Combustion

Carbon dioxide (CO_2) emissions from fossil fuel combustion were estimated using a "bottom-up" methodology characterized by six steps. These steps are described below.

Step 1: Determine Energy Consumption by Fuel Type and Sector

The bottom-up methodology used by the United States for estimating CO_2 emissions from fossil fuel combustion is conceptually similar to the approach recommended by the Intergovernmental Panel on Climate Change (IPCC) for countries that intend to develop detailed, sectoral-based emission estimates (IPCC/UNEP/OECD/IEA 1997). Basic consumption data are presented in Columns 2-8 of Table A-1 through Table A-8, with totals by fuel type in Column 8 and totals by end-use sector in the last rows. Fuel consumption data for the bottom-up approach were obtained directly from the Energy Information Administration (EIA) of the U.S. Department of Energy. The EIA data were collected through surveys at the point of delivery or use; therefore, they reflect the reported consumption of fuel by end-use sector and fuel type. Individual data elements were supplied by a variety of sources within EIA. Most information was taken from published reports, although some data were drawn from unpublished energy studies and databases maintained by EIA.

Energy consumption data were aggregated by end-use sector (i.e., residential, commercial, industrial, transportation, electric utilities, and U.S. territories), primary fuel type (e.g., coal, natural gas, and petroleum), and secondary fuel type (e.g., motor gasoline, distillate fuel, etc.). The 1997 total energy consumption across all sectors, including territories, and energy types was 80,469 trillion British thermal units (TBtu), as indicated in the last entry of Column 8 in Table A-1. This total includes fuel used for non-energy purposes and fuel consumed as international bunkers, both of which are deducted in later steps.

There are two modifications made in this report that may cause consumption information herein to differ from figures given in the cited literature. These are the consideration of synthetic natural gas production and ethanol added to motor gasoline.

First, a portion of industrial coal accounted for in EIA combustion figures is actually used to make "synthetic natural gas" via coal gasification. The energy in this gas enters the natural gas stream, and is accounted for in natural gas consumption statistics. Because this energy is already accounted for as natural gas, it is deducted from industrial coal consumption to avoid double counting. This makes the figure for other industrial coal consumption in this report slightly lower than most EIA sources.

Second, ethanol has been added to the motor gasoline stream for several years, but prior to 1993 this addition was not captured in EIA motor gasoline statistics. Starting in 1993, ethanol was included in gasoline statistics. However, because ethanol is a biofuel, which is assumed to result in no net CO_2 emissions, the amount of ethanol added is subtracted from total gasoline consumption. Thus, motor gasoline consumption statistics given in this report may be slightly lower than in EIA sources.

There are also three basic differences between the consumption figures presented in Table A-1 through Table A-8 and those recommended in the IPCC emission inventory methodology.

First, consumption data in the U.S. inventory are presented using higher heating values (HHV)[1] rather than the lower heating values (LHV)[2] reflected in the IPCC emission inventory methodology. This convention is followed because data obtained from EIA are based on HHV.

[1] Also referred to as Gross Calorific Values (GCV).

[2] Also referred to as Net Calorific Values (NCV).

Second, while EIA's energy use data for the United States includes only the 50 U.S. states and the District of Columbia, the data reported to the Framework Convention on Climate Change are to include energy consumption within territories. Therefore, consumption estimates for U.S. territories were added to domestic consumption of fossil fuels. Energy consumption data from U.S. territories are presented in Column 7 of Table A-1. It is reported separately from domestic sectoral consumption, because it is collected separately by EIA with no sectoral disaggregation.

Third, the domestic sectoral consumption data in Table A-1 include bunker fuels used for international transport activities and non-energy uses of fossil fuels. The IPCC recommends that countries estimate emissions from bunker fuels separately and exclude these emissions from national totals, so bunker fuel emissions have been estimated in Table A-9 and deducted from national estimates (see Step 4). Similarly, fossil fuels used to produce non-energy products that store carbon rather than release it to the atmosphere are provided in Table A-10 and deducted from national emission estimates (see Step 3).

Step 2: Determine the Carbon Content of All Fuels

The carbon content of combusted fossil fuels was estimated by multiplying energy consumption (Columns 2 through 8 of Table A-1) by fuel-specific carbon content coefficients (see Table A-11 and Table A-12) that reflected the amount of carbon per unit of energy inherent in each fuel. The resulting carbon contents are sometimes referred to as potential emissions, or the maximum amount of carbon that could potentially be released to the atmosphere if all carbon in the fuels were converted to CO_2. The carbon content coefficients used in the U.S. inventory were derived by EIA from detailed fuel information and are similar to the carbon content coefficients contained in the IPCC's default methodology (IPCC/UNEP/OECD/IEA 1997), with modifications reflecting fuel qualities specific to the United States.

Step 3: Adjust for the amount of Carbon Stored in Products

Depending on the end-use, non-energy uses of fossil fuels can result in long term storage of some or all of the carbon contained in the fuel. For example, asphalt made from petroleum can sequester up to 100 percent of the carbon contained in the petroleum feedstock for extended periods of time. Other non-energy products, such as lubricants or plastics also store carbon, but can lose or emit some of this carbon when they are used and/or burned as waste.

The amount of carbon sequestered or stored by non-energy uses of fossil fuel products was based upon data that addressed the ultimate fate of various energy products, with all non-energy use attributed to the industrial, transportation, and territories end-use sectors. This non-energy consumption is presented in Table A-10. Non-energy consumption was then multiplied by fuel-specific carbon content coefficients (Table A-11 and Table A-12) to obtain the carbon content of the fuel, or the maximum amount of carbon that could be sequestered if all the carbon in the fuel were stored in non-energy products (Columns 5 and 6 of Table A-10). This carbon content was then multiplied by the fraction of carbon assumed to actually have been sequestered in products (Column 7 of Table A-10), resulting in the final estimates of carbon stored by sector and fuel type, which are presented in Columns 8 through 10 of Table A-10. The portions of carbon sequestered were based on EIA data.

Step 4: Subtract Carbon from Bunker Fuels.

Emissions from international transport activities, or bunker fuel consumption, were not included in national totals as recommended by the IPCC (IPCC/UNEP/OECD/IEA 1997). There is currently disagreement internationally as to how these emissions should be allocated, and until this issue is resolved, countries are asked to report them separately. EIA energy statistics, however, include bunker fuels—jet fuel, distillate fuel oil, and residual fuel oil—as part of fuel consumption by the transportation sector. To compensate for this inclusion, bunker fuel emissions were calculated separately (see Table A-9) and the carbon content of these fuels was subtracted from the transportation sector. The calculations of bunker fuel emissions followed the same procedures used for other fuel emissions (i.e., estimation of consumption, determination of carbon content, and adjustment for the fraction of carbon not oxidized).

Step 5: Account for Carbon that Does Not Oxidize During Combustion

Because combustion processes are not 100 percent efficient, some of the carbon contained in fuels is not emitted to the atmosphere. Rather, it remains behind as soot, particulate matter, ash, or other by-products of inefficient combustion. The estimated fraction of carbon not oxidized in U.S. energy conversion processes due to inefficiencies during combustion ranges from 0.5 percent for natural gas to 1 percent for petroleum and coal. Except for coal these assumptions are consistent with the default values recommended by the IPCC (IPCC/UNEP/OECD/IEA 1997). In the U.S. unoxidized carbon from coal combustion was estimated to be no more than one percent (Bechtel 1993). Table A-11 presents fractions oxidized by fuel type, which are multiplied by the net carbon content of the combusted energy to give final emissions estimates.

Step 6: Summarize Emission Estimates

Actual CO_2 emissions in the United States were summarized by major fuel (i.e., coal, petroleum, natural gas, geothermal) and consuming sector (i.e., residential, commercial, industrial, transportation, electric utilities, and territories). Adjustments for bunker fuels and carbon sequestered in products were made. Emission estimates are expressed in terms of million metric tons of carbon equivalents (MMTCE).

To determine total emissions by final end-use sector, emissions from electric utilities were distributed to each end-use sector according to its share of electricity consumed (see Table A-13).

Table A-1: 1997 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)							Emissions (MMTCE) including Adjustments* and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Residential Coal	55.1						55.1	1.4						1.4
Commercial Coal		83.1					83.1		2.1					2.1
Industrial Coking Coal			789.1				789.1			19.4				19.4
Industrial Other Coal			1,495.7				1,495.7			38.6				38.6
Coke Imports			18.2				18.2			0.5				0.5
Transportation Coal				0.0			0.0				0.0			0.0
Utility Coal					18,480.0		18,480.0					470.9		470.9
US Territory Coal (bit)						10.7	10.7						0.3	0.3
Total Coal	**55.1**	**83.1**	**2,303.0**	**0.0**	**18,480.0**	**10.7**	**20,932**	**1.4**	**2.1**	**58.5**	**0.0**	**470.9**	**0.3**	**533.3**
Natural Gas	**5,145.6**	**3,373.1**	**10,285.5**	**731.5**	**3,039.7**	**NA**	**22,575**	**74.1**	**48.6**	**142.5**	**10.5**	**43.8**	**NA**	**319.4**
Asphalt & Road Oil	0.0	0.0	1,223.6	0.0	0.0		1,223.6	0.0	0.0	(0.0)	0.0	0.0	0.0	(0.0)
Aviation Gasoline	0.0	0.0	0.0	39.7	0.0		39.7	0.0	0.0	0.0	0.7	0.0	0.0	0.7
Distillate Fuel Oil	943.5	491.6	1,142.9	4,637.8	88.3	112.8	7,417.0	18.6	9.7	22.1	90.0	1.7	2.2	144.5
Jet Fuel	0.0	0.0	0.0	3,308.2	0.0	73.4	3,381.6	0.0	0.0	0.0	49.4	0.0	1.4	50.8
Kerosene	90.6	26.9	18.8	0.0	0.0		136.3	1.8	0.5	0.4	0.0	0.0	0.0	2.7
LPG	432.9	76.4	2,162.4	17.9	0.0	10.7	2,700.3	7.3	1.3	14.3	0.3	0.0	0.2	23.4
Lubricants	0.0	0.0	182.3	172.1	0.0	0.0	354.4	0.0	0.0	1.8	1.7	0.0	0.0	3.6
Motor Gasoline	0.0	18.8	207.5	15,048.9	0.0	144.7	15,419.9	0.0	0.4	4.0	288.3	0.0	2.8	295.4
Residual Fuel	0.0	117.2	272.2	747.3	691.5	175.5	2,003.7	0.0	2.5	5.7	4.8	14.7	3.7	31.4
Other Petroleum						115.9	115.9						2.1	2.1
AvGas Blend Components			9.1				9.1			0.2				0.2
Crude Oil			4.6				4.6			0.1				0.1
MoGas Blend Components			0.0				0.0			0.0				0.0
Misc. Products			97.8				97.8			2.0				2.0
Naphtha (<401 deg. F)			536.4				536.4			2.4				2.4
Other Oil (>401 deg. F)			861.2				861.2			8.5				8.5
Pentanes Plus			328.9				328.9			1.7				1.7
Petrochemical Feedstocks			0.0				0.0			0.0				0.0
Petroleum Coke			829.1		42.2		871.3			20.4		1.2		21.6
Still Gas			1,447.1				1,447.1			25.1				25.1
Special Naphtha			72.3				72.3			1.4				1.4
Unfinished Oils			(102.9)				(102.9)			(2.1)				(2.1)
Waxes			43.7				43.7			0.9				0.9
Other Wax & Misc.			0.0				0.0			(2.8)				(2.8)
Total Petroleum	**1,466.9**	**730.9**	**9,337.0**	**23,972.0**	**822.0**	**633.1**	**36,961.9**	**27.7**	**14.4**	**106.0**	**435.3**	**17.6**	**12.4**	**613.3**
Geothermal					**0.019**		**0.019**					**0.038**		**0.038**
TOTAL (All Fuels)	**6,667.7**	**4,187.1**	**21,925.5**	**24,703.5**	**22,341.6**	**643.8**	**80,469.1**	**103.2**	**65.1**	**306.9**	**445.8**	**532.3**	**12.6**	**1,466.0**

*Adjustments include: international bunker fuel consumption (see Table A-9) and carbon stored in products (see Table A-10)
NA (Not Available)

Table A-2: 1996 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)							Emissions (MMTCE) including Adjustments* and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Residential Coal	55.1						55.1	1.4						1.4
Commercial Coal		83.1					83.1		2.1					2.1
Industrial Coking Coal			849.7				849.7			21.0				21.0
Industrial Other Coal			1,507.9				1,507.9			38.9				38.9
Coke Imports			(0.3)				(0.3)			(0.0)				(0.0)
Transportation Coal				0.0			0.0				0.0			0.0
Utility Coal					17,952.7		17,952.7					457.5		457.5
US Territory Coal (bit)						10.7	10.7						0.3	0.3
Total Coal	**55.1**	**83.1**	**2,357.3**	**0.0**	**17,952.7**	**10.7**	**20,459**	**1.4**	**2.1**	**59.9**	**0.0**	**457.5**	**0.3**	**521.1**
Natural Gas	**5,382.9**	**3,243.5**	**10,393.7**	**733.7**	**2,797.7**	**NA**	**22,552**	**77.5**	**46.7**	**144.3**	**10.6**	**40.3**	**NA**	**319.3**
Asphalt & Road Oil	0.0	0.0	1,175.9	0.0	0.0		1,175.9	0.0	0.0	(0.0)	0.0	0.0	0.0	(0.0)
Aviation Gasoline	0.0	0.0	0.0	37.4	0.0		37.4	0.0	0.0	0.0	0.7	0.0	0.0	0.7
Distillate Fuel Oil	927.6	483.4	1,118.6	4,546.6	98.4	111.4	7,285.9	18.3	9.5	21.6	88.4	1.9	2.2	142.0
Jet Fuel	0.0	0.0	0.0	3,274.2	0.0	74.5	3,348.7	0.0	0.0	0.0	49.9	0.0	1.4	51.3
Kerosene	85.1	25.3	17.7	0.0	0.0		128.1	1.7	0.5	0.3	0.0	0.0	0.0	2.5
LPG	428.2	75.6	2,138.9	17.7	0.0	10.1	2,670.5	7.2	1.3	14.0	0.3	0.0	0.0	22.9
Lubricants	0.0	0.0	172.5	163.0	0.0	0.0	335.5	0.0	0.0	1.7	1.6	0.0	0.0	3.4
Motor Gasoline	0.0	18.5	204.8	14,881.9	0.0	140.1	15,245.4	0.0	0.4	3.9	285.2	0.0	2.7	292.2
Residual Fuel	0.0	138.1	307.4	900.6	606.0	167.2	2,119.3	0.0	2.9	6.5	8.0	12.9	3.6	33.9
Other Petroleum						109.7	109.7						2.0	2.0
AvGas Blend Components			7.0				7.0			0.1				0.1
Crude Oil			13.7				13.7			0.3				0.3
MoGas Blend Components			0.0				0.0			0.0				0.0
Misc. Products			89.0				89.0			1.8				1.8
Naphtha (<401 deg. F)			479.3				479.3			2.2				2.2
Other Oil (>401 deg. F)			729.6				729.6			7.2				7.2
Pentanes Plus			355.0				355.0			1.8				1.8
Petrochemical Feedstocks			0.0				0.0			0.0				0.0
Petroleum Coke			836.5		20.5		857.0			20.2		0.6		20.8
Still Gas			1,437.1				1,437.1			24.9				24.9
Special Naphtha			74.5				74.5			1.5				1.5
Unfinished Oils			(112.8)				(112.8)			(2.3)				(2.3)
Waxes			48.7				48.7			1.0				1.0
Other Wax & Misc.			0.0				0.0			(2.7)				(2.7)
Total Petroleum	**1,440.9**	**740.9**	**9,093.6**	**23,821.4**	**724.9**	**613.0**	**36,434.6**	**27.2**	**14.6**	**103.9**	**434.1**	**15.4**	**12.0**	**607.2**
Geothermal					**0.018**		**0.018**					**0.037**		**0.037**
TOTAL (All Fuels)	**6,878.9**	**4,067.5**	**21,844.6**	**24,555.0**	**21,475.3**	**623.7**	**79,445.0**	**106.1**	**63.4**	**308.1**	**444.7**	**513.2**	**12.2**	**1,447.7**

*Adjustments include: international bunker fuel consumption (see Table A-9) and carbon stored in products (see Table A-10)
NA (Not Available)

Table A-3: 1995 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)							Emissions (MMTCE) including Adjustments* and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Residential Coal	53.7						53.7	1.4						1.4
Commercial Coal		81.0					81.0		2.1					2.1
Industrial Coking Coal			884.7				884.7			21.8				21.8
Industrial Other Coal			1,530.7				1,530.7			39.6				39.6
Coke Imports			26.4				26.4			0.7				0.7
Transportation Coal				0.0			0.0				0.0			0.0
Utility Coal					16,990.5		16,990.5					433.0		433.0
US Territory Coal (bit)						10.4	10.4						0.3	0.3
Total Coal	**53.7**	**81.0**	**2,441.9**	**0.0**	**16,990.5**	**10.4**	**19,577**	**1.4**	**2.1**	**62.1**	**0.0**	**433.0**	**0.3**	**498.8**
Natural Gas	**4,981.3**	**3,112.9**	**10,108.6**	**722.0**	**3,276.4**	**NA**	**22,201**	**71.7**	**44.8**	**140.4**	**10.4**	**47.2**	**NA**	**314.5**
Asphalt & Road Oil	0.0	0.0	1,178.2	0.0	0.0		1,178.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aviation Gasoline	0.0	0.0	0.0	39.6	0.0		39.6	0.0	0.0	0.0	0.7	0.0	0.0	0.7
Distillate Fuel Oil	893.1	470.3	1,119.3	4,244.4	90.7	121.8	6,939.5	17.6	9.3	21.6	82.2	1.8	2.4	134.9
Jet Fuel	0.0	0.0	0.0	3,132.2	0.0	79.2	3,211.4	0.0	0.0	0.0	47.6	0.0	1.5	49.1
Kerosene	71.7	21.5	18.7	0.0	0.0		111.8	1.4	0.4	0.4	0.0	0.0	0.0	2.2
LPG	398.3	70.3	2,010.8	32.4	0.0	7.9	2,519.6	6.7	1.2	12.7	0.5	0.0	0.1	21.2
Lubricants	0.0	0.0	177.8	167.9	0.0	0.0	345.7	0.0	0.0	1.8	1.7	0.0	0.0	3.5
Motor Gasoline	0.0	25.8	196.7	14,586.4	0.0	137.8	14,946.7	0.0	0.5	3.8	279.9	0.0	2.6	286.7
Residual Fuel	0.0	168.9	371.5	870.0	544.4	180.6	2,135.3	0.0	3.6	7.8	7.1	11.6	3.8	34.0
Other Petroleum						71.2	71.2						1.3	1.3
AvGas Blend Components			5.3				5.3			0.1				0.1
Crude Oil			14.5				14.5			0.3				0.3
MoGas Blend Components			0.0				0.0			0.0				0.0
Misc. Products			97.1				97.1			1.9				1.9
Naphtha (<401 deg. F)			373.0				373.0			1.7				1.7
Other Oil (>401 deg. F)			801.0				801.0			7.9				7.9
Pentanes Plus			337.9				337.9			1.7				1.7
Petrochemical Feedstocks			0.0				0.0			0.0				0.0
Petroleum Coke			802.0		22.9		824.9			19.5		0.6		20.1
Still Gas			1,417.5				1,417.5			24.0				24.0
Special Naphtha			70.8				70.8			1.4				1.4
Unfinished Oils			(320.9)				(320.9)			(6.4)				(6.4)
Waxes			40.6				40.6			0.8				0.8
Other Wax & Misc.			0.0				0.0			(2.7)				(2.7)
Total Petroleum	**1,363.0**	**756.8**	**8,711.6**	**23,072.9**	**658.0**	**598.5**	**35,160.8**	**25.7**	**15.0**	**98.2**	**419.7**	**14.0**	**11.8**	**584.4**
Geothermal					**0.016**		**0.016**					**0.033**		**0.033**
TOTAL (All Fuels)	**6,398.0**	**3,950.7**	**21,262.1**	**23,794.8**	**20,924.9**	**608.9**	**76,939.4**	**98.8**	**61.9**	**300.7**	**430.1**	**494.2**	**12.048**	**1,397.8**

*Adjustments include: international bunker fuel consumption (see Table A-9) and carbon stored in products (see Table A-10)
NA (Not Available)

Table A-4: 1994 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)							Emissions (MMTCE) including Adjustments* and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Residential Coal	55.5						55.5	1.4						1.4
Commercial Coal		83.5					83.5		2.1					2.1
Industrial Coking Coal			850.6				850.6			21.0				21.0
Industrial Other Coal			1,589.4				1,589.4			41.1				41.1
Coke Imports			23.6				23.6			0.7				0.7
Transportation Coal				0.0			0.0				0.0			0.0
Utility Coal					16,895.2		16,895.2					430.2		430.2
US Territory Coal (bit)						10.3	10.3						0.3	0.3
Total Coal	**55.5**	**83.5**	**2,463.7**	**0.0**	**16,895.2**	**10.3**	**19,508**	**1.4**	**2.1**	**62.7**	**0.0**	**430.2**	**0.3**	**496.7**
Natural Gas	**4,988.3**	**2,980.8**	**9,590.2**	**705.2**	**3,052.9**	**NA**	**21,317**	**71.8**	**42.9**	**133.1**	**10.2**	**44.0**	**NA**	**301.9**
Asphalt & Road Oil	0.0	0.0	1,172.9	0.0	0.0		1,172.9	0.0	0.0	(0.0)	0.0	0.0	0.0	(0.0)
Aviation Gasoline	0.0	0.0	0.0	38.1	0.0		38.1	0.0	0.0	0.0	0.7	0.0	0.0	0.7
Distillate Fuel Oil	880.0	464.3	1,108.8	4,175.0	95.2	101.4	6,824.7	17.4	9.2	21.4	80.9	1.9	2.0	132.8
Jet Fuel	0.0	0.0	0.0	3,154.5	0.0	77.2	3,231.7	0.0	0.0	0.0	48.8	0.0	1.5	50.3
Kerosene	64.9	19.5	16.9	0.0	0.0		101.3	1.3	0.4	0.3	0.0	0.0	0.0	2.0
LPG	395.5	69.8	1,996.5	32.2	0.0	9.2	2,503.1	6.7	1.2	13.0	0.5	0.0	0.2	21.5
Lubricants	0.0	0.0	180.9	170.8	0.0	0.0	351.7	0.0	0.0	1.8	1.7	0.0	0.0	3.5
Motor Gasoline	0.0	25.2	191.9	14,214.1	0.0	131.5	14,562.7	0.0	0.5	3.7	273.7	0.0	2.5	280.4
Residual Fuel	0.0	174.6	417.6	896.0	846.6	171.3	2,506.0	0.0	3.7	8.8	4.8	18.0	3.6	39.0
Other Petroleum						72.7	72.7						1.3	1.3
AvGas Blend Components			6.1				6.1			0.1				0.1
Crude Oil			18.7				18.7			0.4				0.4
MoGas Blend Components			0.0				0.0			0.0				0.0
Misc. Products			105.9				105.9			2.1				2.1
Naphtha (<401 deg. F)			398.3				398.3			1.8				1.8
Other Oil (>401 deg. F)			838.6				838.6			8.3				8.3
Pentanes Plus			338.7				338.7			2.4				2.4
Petrochemical Feedstocks			0.0				0.0			0.0				0.0
Petroleum Coke			793.0		26.3		819.4			19.4		0.7		20.1
Still Gas			1,439.4				1,439.4			24.6				24.6
Special Naphtha			81.1				81.1			1.6				1.6
Unfinished Oils			(279.2)				(279.2)			(5.6)				(5.6)
Waxes			40.6				40.6			0.8				0.8
Other Wax & Misc.			0.0				0.0			(2.9)				(2.9)
Total Petroleum	**1,340.4**	**753.3**	**8,866.8**	**22,680.7**	**968.2**	**563.2**	**35,172.6**	**25.3**	**14.9**	**102.0**	**411.2**	**20.6**	**11.1**	**585.2**
Geothermal					**0.024**		**0.024**					**0.049**		**0.049**
TOTAL (All Fuels)	**6,384.2**	**3,817.6**	**20,920.7**	**23,385.9**	**20,916.2**	**573.4**	**75,998.0**	**98.6**	**60.0**	**297.8**	**421.4**	**494.8**	**11.333**	**1,383.9**

*Adjustments include: international bunker fuel consumption (see Table A-9) and carbon stored in products (see Table A-10)
NA (Not Available)

Table A-5: 1993 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)							Emissions (MMTCE) including Adjustments* and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Residential Coal	56.6						56.6	1.5						1.5
Commercial Coal		85.5					85.5		2.2					2.2
Industrial Coking Coal			839.5				839.5			20.7				20.7
Industrial Other Coal			1,588.0				1,588.0			41.1				41.1
Coke Imports			17.3				17.3			0.5				0.5
Transportation Coal				0.0			0.0				0.0			0.0
Utility Coal					16,841.1		16,841.1					428.7		428.7
US Territory Coal (bit)						9.6	9.6						0.2	0.2
Total Coal	**56.6**	**85.5**	**2,444.8**	**0.0**	**16,841.1**	**9.6**	**19,438**	**1.5**	**2.2**	**62.2**	**0.0**	**428.7**	**0.2**	**494.7**
Natural Gas	**5,097.5**	**2,995.8**	**9,419.6**	**643.1**	**2,744.1**	**NA**	**20,900**	**73.4**	**43.1**	**131.7**	**9.3**	**39.5**	**NA**	**297.0**
Asphalt & Road Oil	0.0	0.0	1,149.0	0.0	0.0		1,149.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aviation Gasoline	0.0	0.0	0.0	38.4	0.0		38.4	0.0	0.0	0.0	0.7	0.0	0.0	0.7
Distillate Fuel Oil	912.9	463.9	1,099.7	3,912.9	76.7	92.4	6,558.4	18.0	9.2	21.2	75.7	1.5	1.8	127.4
Jet Fuel	0.0	0.0	0.0	3,028.0	0.0	66.7	3,094.8	0.0	0.0	0.0	46.9	0.0	1.3	48.1
Kerosene	75.6	14.0	13.1	0.0	0.0		102.7	1.5	0.3	0.3	0.0	0.0	0.0	2.0
LPG	398.6	70.3	1,794.4	18.9	0.0	12.8	2,295.1	6.7	1.2	12.1	0.3	0.0	0.2	20.5
Lubricants	0.0	0.0	173.1	163.5	0.0	0.0	336.5	0.0	0.0	1.7	1.6	0.0	0.0	3.4
Motor Gasoline	0.0	29.6	179.4	14,000.5	0.0	116.0	14,325.5	0.0	0.6	3.5	269.3	0.0	2.2	275.5
Residual Fuel	0.0	175.0	451.8	913.4	938.6	153.7	2,632.5	0.0	3.7	9.5	2.4	20.0	3.3	38.9
Other Petroleum						83.3	83.3						1.5	1.5
AvGas Blend Components			0.1				0.1			0.0				0.0
Crude Oil			21.2				21.2			0.4				0.4
MoGas Blend Components			0.0				0.0			0.0				0.0
Misc. Products			94.7				94.7			1.9				1.9
Naphtha (<401 deg. F)			350.6				350.6			1.6				1.6
Other Oil (>401 deg. F)			844.1				844.1			8.3				8.3
Pentanes Plus			332.3				332.3			2.0				2.0
Petrochemical Feedstocks			0.0				0.0			0.0				0.0
Petroleum Coke			767.3		36.8		804.1			18.9		1.0		19.9
Still Gas			1,430.2				1,430.2			24.4				24.4
Special Naphtha			104.6				104.6			2.1				2.1
Unfinished Oils			(396.0)				(396.0)			(7.9)				(7.9)
Waxes			40.0				40.0			0.8				0.8
Other Wax & Misc.			0.0				0.0			(2.7)				(2.7)
Total Petroleum	**1,387.0**	**752.8**	**8,449.6**	**22,075.5**	**1,052.0**	**525.0**	**34,242.1**	**26.2**	**14.9**	**98.0**	**396.9**	**22.5**	**10.3**	**568.8**
Geothermal					**0.026**		**0.026**					**0.053**		**0.053**
TOTAL (All Fuels)	**6,541.1**	**3,834.2**	**20,314.0**	**22,718.6**	**20,637.3**	**534.6**	**74,579.8**	**101.0**	**60.2**	**291.9**	**406.1**	**490.7**	**10.524**	**1,360.6**

*Adjustments include: international bunker fuel consumption (see Table A-9) and carbon stored in products (see Table A-10)
NA (Not Available)

Table A-6: 1992 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)							Emissions (MMTCE) including Adjustments* and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Residential Coal	56.7						56.7	1.5						1.5
Commercial Coal		85.7					85.7		2.2					2.2
Industrial Coking Coal			867.4				867.4			21.2				21.2
Industrial Other Coal			1,573.1				1,573.1			40.7				40.7
Coke Imports			27.2				27.2			0.7				0.7
Transportation Coal				0.0			0.0				0.0			0.0
Utility Coal					16,192.0		16,192.0					411.8		411.8
US Territory Coal (bit)						8.8	8.8						0.2	0.2
Total Coal	**56.7**	**85.7**	**2,467.7**	**0.0**	**16,192.0**	**8.8**	**18,811**	**1.5**	**2.2**	**62.6**	**0.0**	**411.8**	**0.2**	**478.3**
Natural Gas	**4,821.1**	**2,884.2**	**8,996.3**	**608.4**	**2,828.5**	**NA**	**20,138**	**69.4**	**41.5**	**126.1**	**8.8**	**40.7**	**NA**	**286.5**
Asphalt & Road Oil	0.0	0.0	1,102.2	0.0	0.0		1,102.2	0.0	0.0	(0.0)	0.0	0.0	0.0	(0.0)
Aviation Gasoline	0.0	0.0	0.0	41.1	0.0		41.1	0.0	0.0	0.0	0.8	0.0	0.0	0.8
Distillate Fuel Oil	864.9	464.0	1,144.5	3,810.2	67.3	78.2	6,429.1	17.1	9.2	22.1	73.6	1.3	1.5	124.8
Jet Fuel	0.0	0.0	0.0	3,001.3	0.0	61.9	3,063.2	0.0	0.0	0.0	46.6	0.0	1.2	47.8
Kerosene	65.0	11.1	9.8	0.0	0.0		85.9	1.3	0.2	0.2	0.0	0.0	0.0	1.7
LPG	382.5	67.5	1,859.8	18.4	0.0	11.8	2,340.0	6.4	1.1	12.7	0.3	0.0	0.2	20.8
Lubricants	0.0	0.0	170.0	160.5	0.0	0.0	330.5	0.0	0.0	1.7	1.6	0.0	0.0	3.3
Motor Gasoline	0.0	79.5	194.3	13,698.8	0.0	114.4	14,087.0	0.0	1.5	3.7	263.4	0.0	2.2	270.8
Residual Fuel	0.0	191.2	391.3	1,082.0	835.6	154.6	2,654.7	0.0	4.1	8.2	6.7	17.8	3.3	40.0
Other Petroleum						61.4	61.4						1.1	1.1
AvGas Blend Components			0.2				0.2			0.0				0.0
Crude Oil			27.4				27.4			0.5				0.5
MoGas Blend Components			75.7				75.7			1.5				1.5
Misc. Products			100.1				100.1			2.0				2.0
Naphtha (<401 deg. F)			377.3				377.3			1.7				1.7
Other Oil (>401 deg. F)			814.9				814.9			8.1				8.1
Pentanes Plus			322.7				322.7			4.9				4.9
Petrochemical Feedstocks			0.0				0.0			0.0				0.0
Petroleum Coke			813.1		30.1		843.2			19.0		0.8		19.9
Still Gas			1,447.6				1,447.6			24.9				24.9
Special Naphtha			104.6				104.6			2.1				2.1
Unfinished Oils			(355.0)				(355.0)			(7.1)				(7.1)
Waxes			37.3				37.3			0.7				0.7
Other Wax & Misc.			0.0				0.0			(2.7)				(2.7)
Total Petroleum	**1,312.4**	**813.3**	**8,637.7**	**21,812.3**	**933.0**	**482.3**	**33,991.0**	**24.8**	**16.1**	**104.3**	**392.9**	**19.9**	**9.5**	**567.5**
Geothermal					**0.028**		**0.028**					**0.057**		**0.057**
TOTAL (All Fuels)	**6,190.2**	**3,783.2**	**20,101.7**	**22,420.7**	**19,953.5**	**491.2**	**72,940.4**	**95.7**	**59.9**	**292.9**	**401.7**	**472.5**	**9.713**	**1332.4**

*Adjustments include: international bunker fuel consumption (see Table A-9) and carbon stored in products (see Table A-10)
NA (Not Available)

Table A-7: 1991 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)							Emissions (MMTCE) including Adjustments* and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Residential Coal	56.3						56.3	1.4						1.4
Commercial Coal		84.5					84.5		2.2					2.2
Industrial Coking Coal			907.3				907.3			22.6				22.6
Industrial Other Coal			1,629.2				1,629.2			42.0				42.0
Coke Imports			8.9				8.9			0.2				0.2
Transportation Coal				0.0			0.0				0.0			0.0
Utility Coal					16,012.4		16,012.4					407.2		407.2
US Territory Coal (bit)						7.8	7.8						0.2	0.2
Total Coal	**56.3**	**84.5**	**2,545.4**	**0.0**	**16,012.4**	**7.8**	**18,706**	**1.4**	**2.2**	**64.8**	**0.0**	**407.2**	**0.2**	**475.9**
Natural Gas	**4,685.0**	**2,807.7**	**8,637.2**	**621.5**	**2,853.6**	**NA**	**19,605**	**67.5**	**40.4**	**120.5**	**8.9**	**41.1**	**NA**	**278.4**
Asphalt & Road Oil	0.0	0.0	1,076.5	0.0	0.0		1,076.5	0.0	0.0	(0.0)	0.0	0.0	0.0	(0.0)
Aviation Gasoline	0.0	0.0	0.0	41.7	0.0		41.7	0.0	0.0	0.0	0.8	0.0	0.0	0.8
Distillate Fuel Oil	831.5	481.6	1,139.2	3,677.6	80.0	71.4	6,281.3	16.4	9.5	21.9	71.0	1.6	1.4	121.8
Jet Fuel	0.0	0.0	0.0	3,025.0	0.0	78.3	3,103.3	0.0	0.0	0.0	47.6	0.0	1.5	49.1
Kerosene	72.3	12.1	11.4	0.0	0.0		95.8	1.4	0.2	0.2	0.0	0.0	0.0	1.9
LPG	389.5	68.7	1,749.3	19.9	0.0	13.8	2,241.2	6.5	1.2	11.0	0.3	0.0	0.2	19.3
Lubricants	0.0	0.0	166.7	157.5	0.0	0.0	324.2	0.0	0.0	1.7	1.6	0.0	0.0	3.2
Motor Gasoline	0.0	85.0	193.3	13,502.6	0.0	117.0	13,897.9	0.0	1.6	3.7	259.5	0.0	2.2	267.0
Residual Fuel	0.0	213.2	335.9	1,031.9	1,076.1	134.6	2,791.7	0.0	4.5	7.1	6.3	22.9	2.9	43.6
Other Petroleum						122.1	122.1						2.2	2.2
AvGas Blend Components			(0.1)				(0.1)			(0.0)				(0.0)
Crude Oil			38.9				38.9			0.8				0.8
MoGas Blend Components			(25.9)				(25.9)			(0.5)				(0.5)
Misc. Products			152.6				152.6			3.1				3.1
Naphtha (<401 deg. F)			298.9				298.9			1.3				1.3
Other Oil (>401 deg. F)			827.3				827.3			8.2				8.2
Pentanes Plus			294.0				294.0			4.7				4.7
Petrochemical Feedstocks			0.0				0.0			0.0				0.0
Petroleum Coke			700.2		21.7		722.0			17.1		0.6		17.7
Still Gas			1,426.6				1,426.6			24.4				24.4
Special Naphtha			88.0				88.0			1.7				1.7
Unfinished Oils			(450.2)				(450.2)			(9.0)				(9.0)
Waxes			35.1				35.1			0.7				0.7
Other Wax & Misc.			0.0				0.0			(3.7)				(3.7)
Total Petroleum	**1,293.3**	**860.6**	**8,057.8**	**21,456.2**	**1,177.8**	**537.2**	**33,382.9**	**24.4**	**17.1**	**94.3**	**387.0**	**25.1**	**10.4**	**558.3**
Geothermal					**0.028**		**0.028**					**0.057**		**0.057**
TOTAL (All Fuels)	**6,034.6**	**3,752.8**	**19,240.4**	**22,077.7**	**20,043.8**	**544.9**	**71,694.3**	**93.3**	**59.7**	**279.6**	**396.0**	**473.5**	**10.606**	**1,312.6**

*Adjustments include: international bunker fuel consumption (see Table A-9) and carbon stored in products (see Table A-10)
NA (Not Available)

Table A-8: 1990 Energy Consumption Data and CO_2 Emissions from Fossil Fuel Combustion by Fuel Type

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	Consumption (TBtu)							Emissions (MMTCE) including Adjustments* and Fraction Oxidized						
Fuel Type	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**	**Res.**	**Comm.**	**Ind.**	**Trans.**	**Utility**	**Terr.**	**Total**
Residential Coal	61.9						61.9	1.6						1.6
Commercial Coal		92.9					92.9		2.4					2.4
Industrial Coking Coal			1,041.8				1,041.8			25.9				25.9
Industrial Other Coal			1,646.1				1,646.1			42.4				42.4
Coke Imports			4.8				4.8			0.1				0.1
Transportation Coal				0.0			0.0				0.0			0.0
Utility Coal					16,087.8		16,087.8					409.0		409.0
US Territory Coal (bit)						7.0	7.0						0.2	0.2
Total Coal	**61.9**	**92.9**	**2,692.7**	**0.0**	**16,087.8**	**7.0**	**18,942**	**1.6**	**2.4**	**68.5**	**0.0**	**409.0**	**0.2**	**481.6**
Natural Gas	**4,518.7**	**2,698.1**	**8,519.7**	**682.4**	**2,861.4**	**NA**	**19,280**	**65.1**	**38.8**	**118.6**	**9.8**	**41.2**	**NA**	**273.5**
Asphalt & Road Oil	0.0	0.0	1,170.2	0.0	0.0		1,170.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aviation Gasoline	0.0	0.0	0.0	45.0	0.0		45.0	0.0	0.0	0.0	0.8	0.0	0.0	0.8
Distillate Fuel Oil	837.4	487.0	1,180.9	3,830.5	86.3	74.0	6,496.1	16.5	9.6	22.9	74.2	1.7	1.5	126.4
Jet Fuel	0.0	0.0	0.0	3,129.5	0.0	61.0	3,190.5	0.0	0.0	0.0	49.6	0.0	1.2	50.8
Kerosene	63.9	11.8	12.3	0.0	0.0		88.0	1.2	0.2	0.2	0.0	0.0	0.0	1.7
LPG	365.0	64.4	1,607.7	21.8	0.0	14.4	2,073.3	6.1	1.1	11.0	0.4	0.0	0.2	18.8
Lubricants	0.0	0.0	186.3	176.0	0.0	0.0	362.3	0.0	0.0	1.9	1.8	0.0	0.0	3.6
Motor Gasoline	0.0	110.6	184.1	13,577.1	0.0	101.0	13,972.8	0.0	2.1	3.5	260.9	0.0	1.9	268.5
Residual Fuel	0.0	233.1	417.2	1,030.2	1,139.4	121.8	2,941.7	0.0	5.0	8.8	6.8	24.2	2.6	47.3
Other Petroleum						85.9	85.9						1.5	1.5
AvGas Blend Components			0.2				0.2			0.0				0.0
Crude Oil			50.9				50.9			1.0				1.0
MoGas Blend Components			53.7				53.7			1.0				1.0
Misc. Products			137.8				137.8			2.8				2.8
Naphtha (<401 deg. F)			347.8				347.8			1.6				1.6
Other Oil (>401 deg. F)			753.9				753.9			7.4				7.4
Pentanes Plus			250.3				250.3			3.3				3.3
Petrochemical Feedstocks			0.0				0.0			0.0				0.0
Petroleum Coke			719.9		24.7		744.6			17.3		0.7		18.0
Still Gas			1,473.2				1,473.2			25.2				25.2
Special Naphtha			107.1				107.1			2.1				2.1
Unfinished Oils			(369.0)				(369.0)			(7.4)				(7.4)
Waxes			33.3				33.3			0.7				0.7
Other Wax & Misc.			0.0				0.0			(3.4)				(3.4)
Total Petroleum	**1,266.3**	**906.9**	**8,317.9**	**21,810.1**	**1,250.4**	**458.2**	**34,009.8**	**23.9**	**18.0**	**100.0**	**394.5**	**26.6**	**8.9**	**572.0**
Geothermal					**0.029**		**0.029**					**0.060**		**0.060**
TOTAL (All Fuels)	**5,846.9**	**3,697.9**	**19,530.3**	**22,492.5**	**20,199.6**	**465.2**	**72,232.4**	**90.6**	**59.2**	**287.1**	**404.3**	**476.9**	**9.098**	**1,327.2**

*Adjustments include: international bunker fuel consumption (see Table A-9) and carbon stored in products (see Table A-10)
NA (Not Available)

Table A-9: 1997 Emissions From International Bunker Fuel Consumption

Fuel Type	Bunker Fuel Consumption (TBtu)	Carbon Content Coefficient (MMTCE/QBtu)[3]	Carbon Content (MMTCE)	Fraction Oxidized	Emissions (MMTCE)
Distillate Fuel Oil	79.4	19.95	1.6	0.99	1.6
Jet Fuel	726.5	19.33	14.0	0.99	13.9
Residual Fuel Oil	523.2	21.49	11.2	0.99	11.1
Total	**1,329.1**		**26.9**		**26.6**

Table A-10: 1997 Non-Energy Use Carbon Stored In Products

1	2	3	4	5	6	7	8	9	10
	Non-energy Use (TBtu)		Carbon Content Coefficient	Carbon Content (MMTCE)		Fraction Sequestered	Carbon Stored (MMTCE)		
Fuel Type	**Ind.**	**Trans.**	**(MMTCE/QBtu)**	**Ind.**	**Trans.**		**Ind.**	**Trans.**	**Total**
Industrial Coking Coal	27.7		25.55	0.7	0.0	0.75	0.5	0.0	0.5
Natural Gas	391.4		14.47	5.7	0.0	1.00	5.7	0.0	5.7
Asphalt & Road Oil	1,223.6		20.62	25.2	0.0	1.00	25.2	0.0	25.2
LPG	1,651.3		16.86	27.8	0.0	0.80	22.3	0.0	22.3
Lubricants	182.3	172.1	20.24	3.7	3.5	0.50	1.8	1.7	3.6
Pentanes Plus	295.4		18.24	5.4	0.0	0.80	4.3	0.0	4.3
Petrochemical Feedstocks									
Naphtha (<401 deg. F)	536.4		18.14	9.7	0.0	0.75	7.3	0.0	7.3
Other Oil (>401 deg. F)	861.2		19.95	17.2	0.0	0.50	8.6	0.0	8.6
Still Gas	2.5		17.51	0.0	0.0	0.80	0.0	0.0	0.0
Petroleum Coke	179.0		27.85	5.0	0.0	0.50	2.5	0.0	2.5
Special Naphtha	72.3		19.86	1.4	0.0	0.00	0.0	0.0	0.0
Other Wax & Misc.									
Distillate Fuel Oil	46.6		19.95	0.9	0.0	0.50	0.5	0.0	0.5
Residual Fuel Oil	7.5		21.49	0.2	0.0	0.50	0.1	0.0	0.1
Waxes	43.7		19.81	0.9	0.0	1.00	0.9	0.0	0.9
Miscellaneous	97.7		20.23	2.0	0.0	1.00	2.0	0.0	2.0
Total	**5,618.6**	**172.1**		**105.8**	**3.5**		**81.7**	**1.7**	**83.4**

[3] One QBtu is one quadrillion Btu, or 10^{15} Btu. This unit is commonly referred to as a "Quad."

Table A-11: Key Assumptions for Estimating Carbon Dioxide Emissions

Fuel Type	Carbon Content Coefficient (MMTCE/QBtu)	Fraction Oxidized
Coal		
Residential Coal	[a]	0.99
Commercial Coal	[a]	0.99
Industrial Coking Coal	[a]	0.99
Industrial Other Coal	[a]	0.99
Coke Imports	27.85	0.99
Transportation Coal	NC	0.99
Utility Coal	[a]	0.99
U.S. Territory Coal (bit)	25.14	0.99
Natural Gas	14.47	0.995
Petroleum		
Asphalt & Road Oil	20.62	0.99
Aviation Gasoline	18.87	0.99
Distillate Fuel Oil	19.95	0.99
Jet Fuel	[a]	0.99
Kerosene	19.72	0.99
LPG	[a]	0.99
Lubricants	20.24	0.99
Motor Gasoline	[a]	0.99
Residual Fuel	21.49	0.99
Other Petroleum	20.23	0.99
AvGas Blend Components	18.87	0.99
Crude Oil	[a]	0.99
MoGas Blend Components	19.39	0.99
Misc. Products	20.23	0.99
Naphtha (<401 deg. F)	18.14	0.99
Other Oil (>401 deg. F)	19.95	0.99
Pentanes Plus	18.24	0.99
Petrochemical Feedstocks	19.37	0.99
Petroleum Coke	27.85	0.99
Still Gas	17.51	0.99
Special Naphtha	19.86	0.99
Unfinished Oils	20.23	0.99
Waxes	19.81	0.99
Other Wax & Misc.	19.81	0.99
Geothermal	2.05	-

Sources: Carbon coefficients and stored carbon from EIA. Combustion efficiency for coal from Bechtel (1993) and for petroleum and natural gas from IPCC (IPCC/UNEP/OECD/IEA 1997, vol. 2).

- Not applicable

NC (Not Calculated)

[a] These coefficients vary annually due to fluctuations in fuel quality (see Table A-12).

Table A-12: Annually Variable Carbon Content Coefficients by Year (MMTCE/QBtu)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997
Residential Coal	25.92	26.00	26.13	25.97	25.95	26.00	25.92	25.92
Commercial Coal	25.92	26.00	26.13	25.97	25.95	26.00	25.92	25.92
Industrial Coking Coal	25.51	25.51	25.51	25.51	25.52	25.53	25.55	25.55
Industrial Other Coal	25.58	25.60	25.62	25.61	25.63	25.63	25.61	25.61
Utility Coal	25.68	25.69	25.69	25.71	25.72	25.74	25.74	25.74
LPG	16.99	16.98	16.99	16.97	17.01	17.00	16.99	16.99
Motor Gasoline	19.41	19.41	19.42	19.43	19.45	19.38	19.36	19.35
Jet Fuel	19.40	19.40	19.39	19.37	19.35	19.34	19.33	19.33
Crude Oil	20.16	20.18	20.22	20.22	20.21	20.23	20.25	20.24

Source: EIA

Table A-13: Electricity Consumption by End-Use Sector (Billion Kilowatt-hours)

End-Use Sector	1990	1991	1992	1993	1994	1995	1996	1997
Residential	924	955	936	995	1,008	1,043	1,082	1,072
Commercial	839	856	851	886	914	954	981	1,008
Industrial	946	947	973	977	1,008	1,013	1,030	1,036
Transportation	4	4	4	4	4	4	4	4
U.S. Territories*	-	-	-	-	-	-	-	-
Total	**2,713**	**2,762**	**2,763**	**2,861**	**2,935**	**3,013**	**3,098**	**3,120**

*EIA electric utility fuel consumption data does not include the U.S. territories.

- Not applicable

Source: EIA

Annex B

Methodology for Estimating Emissions of CH_4, N_2O, and Criteria Pollutants from Stationary Sources

Estimates of CH_4 and N_2O Emissions

Methane (CH_4) and nitrous oxide (N_2O) emissions from stationary source fuel combustion were estimated using IPCC emission factors and methods. Estimates were obtained by multiplying emission factors (by sector and fuel type) by fossil fuel and wood consumption data. This "top-down" methodology is characterized by two basic steps, described below. Data are presented in Table B-1 through Table B-5.

Step 1: Determine Energy Consumption by Sector and Fuel Type

Greenhouse gas emissions from stationary combustion activities were grouped into four sectors: industrial, commercial/institutional, residential, and electric utilities. For CH_4 and N_2O, estimates were based upon consumption of coal, gas, oil, and wood. Energy consumption data were obtained from EIA's *Monthly Energy Review* (1998b), and adjusted to lower heating values assuming a 10 percent reduction for natural gas and a 5 percent reduction for coal and petroleum fuels. Table B-1 provides annual energy consumption data for the years 1990 through 1997.

Step 2: Determine the Amount of CH_4 and N_2O Emitted

Activity data for each sector and fuel type were then multiplied by emission factors to obtain emissions estimates. Emission factors were taken from the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). Table B-2 provides emission factors used for each sector and fuel type.

Estimates of NO_x, CO, and NMVOC Emissions

For criteria pollutants, the major source categories included were those identified in EPA (1998): coal, fuel oil, natural gas, wood, other fuels (including bagasse, liquefied petroleum gases, coke, coke oven gas, and others), and stationary internal combustion (which includes emissions from internal combustion engines not used in transportation). EPA (1998) periodically estimates emissions of NO_x, CO, and NMVOCs by sector and fuel type using a "bottom-up" estimating procedure. In other words, the emissions were calculated either for individual sources (e.g., industrial boilers) or for many sources combined, using basic activity data (e.g., fuel consumption or deliveries, etc.) as indicators of emissions. EPA (1998) projected emissions for years subsequent to their bottom-up estimates. The national activity data used to calculate the individual categories were obtained from various sources. Depending upon the category, these activity data may include fuel consumption or deliveries of fuel, tons of refuse burned, raw material processed, etc. Activity data were used in conjunction with emission factors that relate the quantity of emissions to the activity. Table B-3 through Table B-7 present criteria pollutant emission estimates for 1990 through 1997.

The basic calculation procedure for most source categories presented in EPA (1998) is represented by the following equation:

$$E_{p,s} = A_s \times Ef_{p,s} \times (1 - C_{p,s}/100)$$

where,

E = emissions
p = pollutant
s = source category
A = activity level
EF = emission factor
C = percent control efficiency

The EPA currently derives the overall emission control efficiency of a category from a variety of sources, including published reports, the 1985 National Acid Precipitation and Assessment Program (NAPAP) emissions inventory, and other EPA databases. The U.S. approach for estimating emissions of NO_x, CO, and NMVOCs from stationary combustion as described above is similar to the methodology recommended by the IPCC (IPCC/UNEP/OECD/IEA 1997).

Table B-1: Fuel Consumption by Stationary Sources for Calculating CH_4 and N_2O Emissions (TBtu)

Fuel/End-Use Sector	1990	1991	1992	1993	1994	1995	1996	1997
Coal	**18,935.3**	**18,698.6**	**18,802.1**	**19,428.0**	**19,497.8**	**19,567.0**	**20,448.3**	**20,921.1**
Residential	61.9	56.3	56.7	56.6	55.5	53.7	55.1	55.1
Commercial/Institutional	92.9	84.5	85.7	85.5	83.5	81.0	83.1	83.1
Industry	2,692.7	2,545.4	2,467.7	2,444.8	2,463.7	2,441.9	2,357.3	2,303.0
Utilities	16,087.8	16,012.4	16,192.0	16,841.1	16,895.2	16,990.5	17,952.7	18,480.0
Petroleum	**11,741.5**	**11,389.6**	**11,696.4**	**11,641.5**	**11,928.7**	**11,489.4**	**12,000.2**	**12,356.8**
Residential	1,266.3	1,293.3	1,312.4	1,387.0	1,340.4	1,363.0	1,440.9	1,466.9
Commercial/Institutional	906.9	860.6	813.3	752.8	753.3	756.8	740.9	730.9
Industry	8,317.9	8,057.8	8,637.7	8,449.6	8,866.8	8,711.6	9,093.6	9,337.0
Utilities	1,250.4	1,177.8	933.0	1,052.0	968.2	658.0	724.9	822.0
Natural Gas	**18,597.9**	**18,983.5**	**19,530.1**	**20,257.1**	**20,612.1**	**21,479.2**	**21,817.8**	**21,843.9**
Residential	4,518.7	4,685.0	4,821.1	5,097.5	4,988.3	4,981.3	5,382.9	5,145.6
Commercial/Institutional	2,698.1	2,807.7	2,884.2	2,995.8	2,980.8	3,112.9	3,243.5	3,373.1
Industry	8,519.7	8,637.2	8,996.3	9,419.6	9,590.2	10,108.6	10,393.7	10,285.5
Utilities	2,861.4	2,853.6	2,828.5	2,744.1	3,052.9	3,276.4	2,797.7	3,039.7
Wood	**2550.0**	**2577.0**	**2709.0**	**2696.0**	**2740.7**	**2741.5**	**2864.0**	**2625.9**
Residential & Commercial	581.0	613.0	645.0	592.0	582.0	641.0	643.8	475.1
Industrial	1947.5	1942.8	2042.4	2083.5	2138.2	2083.5	2200.5	2131.5
Utilities	21.5	21.2	21.6	20.5	20.5	17.0	19.8	19.3

Table B-2: CH_4 and N_2O Emission Factors by Fuel Type and Sector (g/GJ)[4]

Fuel/End-Use Sector	CH_4	N_2O
Coal		
Residential	300	1.4
Commercial/Institutional	10	1.4
Industry	10	1.4
Utilities	1	1.4
Petroleum		
Residential	10	0.6
Commercial/Institutional	10	0.6
Industry	2	0.6
Utilities	3	0.6
Natural Gas		
Residential	5	0.1
Commercial/Institutional	5	0.1
Industry	5	0.1
Utilities	1	0.1
Wood		
Residential	300	4.0
Commercial/Institutional	300	4.0
Industrial	30	4.0
Utilities	30	4.0

[4] GJ (Gigajoule) = 10^9 joules. One joule = 9.486×10^{-4} Btu

Table B-3: NO_x Emissions from Stationary Sources (Gg)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997
Electric Utilities	**6,045**	**5,914**	**5,901**	**6,034**	**5,956**	**5,792**	**5,497**	**5,605**
Coal	5,119	5,043	5,062	5,211	5,113	5,061	5,027	5,079
Fuel Oil	200	192	154	163	148	87	94	120
Natural gas	513	526	526	500	536	510	239	262
Wood	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	213	152	159	160	159	134	137	144
Industrial	**2,754**	**2,703**	**2,786**	**2,859**	**2,855**	**2,852**	**2,876**	**2,967**
Coal	530	517	521	534	546	541	543	557
Fuel Oil	240	215	222	222	219	224	223	218
Natural gas	1,072	1,134	1,180	1,207	1,210	1,202	1,212	1,256
Wood	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	119	117	115	113	113	111	113	118
Internal Combustion	792	720	748	783	767	774	784	818
Commercial/Institutional	**336**	**333**	**348**	**360**	**365**	**365**	**366**	**379**
Coal	36	33	35	37	36	35	35	36
Fuel Oil	88	80	84	84	86	94	93	97
Natural gas	181	191	204	211	215	210	212	219
Wood	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	31	29	25	28	28	27	26	27
Residential	**749**	**829**	**879**	**827**	**817**	**813**	**804**	**779**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA
Wood	42	45	48	40	40	44	44	31
Other Fuels[a]	708	784	831	787	777	769	760	748
Total	**9,884**	**9,779**	**9,914**	**10,080**	**9,993**	**9,822**	**9,543**	**9,729**

NA (Not Available)

[a] "Other Fuels" include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 1998).

[b] Coal, fuel oil, and natural gas emissions are included in the "Other Fuels" category (EPA 1998).

Note: Totals may not sum due to independent rounding.

Table B-4: CO Emissions from Stationary Sources (Gg)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997
Electric Utilities	**329**	**317**	**318**	**329**	**335**	**338**	**357**	**368**
Coal	213	212	214	224	224	227	225	230
Fuel Oil	18	17	14	15	13	9	10	11
Natural gas	46	46	47	45	48	49	69	71
Wood	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	52	41	43	46	50	52	53	56
Industrial	**798**	**835**	**867**	**946**	**944**	**958**	**972**	**1,007**
Coal	95	92	92	92	91	88	90	91
Fuel Oil	67	54	58	60	60	64	65	66
Natural gas	205	257	272	292	306	313	316	329
Wood	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	253	242	239	259	260	270	277	288
Internal Combustion	177	189	205	243	228	222	224	233
Commercial/Institutional	**205**	**196**	**204**	**207**	**212**	**211**	**227**	**235**
Coal	13	13	13	14	13	14	14	14
Fuel Oil	16	16	16	16	16	17	17	17
Natural gas	40	40	46	48	49	49	49	51
Wood	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	136	128	128	129	134	132	148	152
Residential	**3,668**	**3,965**	**4,195**	**3,586**	**3,515**	**3,876**	**3,867**	**2,759**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA
Wood	3,430	3,711	3,930	3,337	3,272	3,628	3,622	2,520
Other Fuels[a]	238	255	265	249	243	248	244	239
Total	**4,999**	**5,313**	**5,583**	**5,068**	**5,007**	**5,383**	**5,424**	**4,369**

NA (Not Available)

[a] "Other Fuels" include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 1998).

[b] Coal, fuel oil, and natural gas emissions are included in the "Other Fuels" category (EPA 1998).

Note: Totals may not sum due to independent rounding.

Table B-5: NMVOC Emissions from Stationary Sources (Gg)

Sector/Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997
Electric Utilities	**43**	**40**	**40**	**41**	**41**	**40**	**44**	**46**
Coal	25	25	25	26	26	26	25	26
Fuel Oil	5	5	4	4	4	2	3	3
Natural gas	2	2	2	2	2	2	7	7
Wood	NA	NA	NA	NA	NA	NA	NA	NA
Internal Combustion	11	9	9	9	9	9	9	9
Industrial	**165**	**177**	**169**	**169**	**178**	**187**	**189**	**197**
Coal	7	5	7	5	7	5	5	5
Fuel Oil	11	10	11	11	11	11	11	11
Natural gas	52	54	47	46	57	66	66	70
Wood	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	46	47	45	46	45	45	46	48
Internal Combustion	49	61	60	60	58	59	60	62
Commercial/Institutional	**18**	**18**	**20**	**22**	**21**	**21**	**21**	**22**
Coal	1	1	1	1	1	1	1	1
Fuel Oil	3	2	3	3	3	3	3	3
Natural gas	7	8	9	10	10	10	10	10
Wood	NA	NA	NA	NA	NA	NA	NA	NA
Other Fuels[a]	8	7	7	8	8	8	8	8
Residential	**686**	**739**	**782**	**670**	**657**	**726**	**724**	**515**
Coal[b]	NA	NA	NA	NA	NA	NA	NA	NA
Fuel Oil[b]	NA	NA	NA	NA	NA	NA	NA	NA
Natural Gas[b]	NA	NA	NA	NA	NA	NA	NA	NA
Wood	651	704	746	633	621	689	687	478
Other Fuels[a]	35	35	36	36	36	37	37	37
Total	**912**	**975**	**1,011**	**901**	**898**	**973**	**978**	**780**

NA (Not Available)

[a] "Other Fuels" include LPG, waste oil, coke oven gas, coke, and non-residential wood (EPA 1998).

[b] Coal, fuel oil, and natural gas emissions are included in the "Other Fuels" category (EPA 1998).

Note: Totals may not sum due to independent rounding.

Annex C

Methodology for Estimating Emissions of CH_4, N_2O, and Criteria Pollutants from Mobile Sources

Estimates of CH_4 and N_2O Emissions

Greenhouse gas emissions from mobile sources are reported by transport mode (e.g., road, rail, air, and water), vehicle type, and fuel type. EPA does not systematically track emissions of CH_4 and N_2O as in EPA (1998a); therefore, estimates of these gases were developed using a methodology similar to that outlined in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997).

Step 1: Determine Vehicle Miles Traveled or Fuel Consumption by Vehicle Type, Fuel Type, and Model Year

Activity data were obtained from a number of U.S. government agency publications. Depending on the category, these basic activity data included such information as fuel consumption, fuel deliveries, and vehicle miles traveled (VMT). The activity data for highway vehicles included estimates of VMT by vehicle type and model year from EPA (1998a) and the MOBILE5a emissions model (EPA 1997).

National VMT data for gasoline and diesel highway vehicles are presented in Table C-1 and Table C-2, respectively. Total VMT for each highway category (i.e., gasoline passenger cars, light-duty gasoline trucks, heavy-duty gasoline vehicles, diesel passenger cars, light-duty diesel trucks, heavy-duty diesel vehicles, and motorcycles) were distributed across 25 model years based on the temporally fixed age distribution of VMT by the U.S. vehicle fleet in 1990 (see Table C-3) as specified in MOBILE5a. Activity data for gasoline passenger cars and light-duty trucks in California were developed separately due to the different emission control technologies deployed in that state relative to the rest of the country. Unlike the rest of the United States, beginning in model year 1994, a fraction of the computed California VMT for gasoline passenger cars and light-duty trucks was attributed to low emission vehicles (LEVs). LEVs have not yet been widely deployed in other states. Based upon U.S. Department of Transportation statistics for 1994, it was assumed that 8.7 percent of national VMT occurred in California.

Activity data for non-highway vehicles were based on annual fuel consumption statistics by transportation mode and fuel type. Consumption data for distillate and residual fuel oil by ships and boats (i.e., vessel bunkering), construction equipment, farm equipment, and locomotives were obtained from EIA (1998). In the case of ships and boats, the EIA (1998) vessel bunkering data was reduced by the amount of fuel used for international bunkers.[5] Data on the consumption of jet fuel in aircraft were obtained directly from EIA, as described under CO_2 from Fossil Fuel Combustion, and were reduced by the amount allocated to international bunker fuels using data from DOT/BTS (1998). Data on aviation gasoline consumed in aircraft were also taken directly from EIA as above. Data on the consumption of motor gasoline by ships and boats, construction equipment, farm equipment, and locomotives data were drawn from FHWA (1997). For these vehicles, 1996 fuel consumption data were used as a proxy because 1997 data were unavailable. The activity data used for non-highway vehicles are included in Table C-4.

Step 2: Allocate VMT Data to Control Technology Type for Highway Vehicles

For highway sources, VMT by vehicle type for each model year were distributed across various control technologies as shown in Table C-5, Table C-6, Table C-7, Table C-8, and Table C-9. Again, California gasoline-fueled passenger cars and light-duty trucks were treated separately due to that state's distinct mobile source emission standards—including the introduction of Low Emission Vehicles (LEVs) in 1994—compared with the rest of the United States. The categories "Tier 0" and "Tier 1" have been substituted for the early three-way catalyst and advanced three-way catalyst categories, respectively, as defined in the *Revised 1996 IPCC Guidelines*. Tier 0, Tier 1, and LEV

[5] See International Bunker Fuels.

are actually U.S. emission regulations, rather than control technologies; however, each does correspond to particular combinations of control technologies and engine design. Tier 1 and its predecessor Tier 0 both apply to vehicles equipped with three-way catalysts. The introduction of "early three-way catalysts," and "advance three-way catalysts" as described in the *Revised 1996 IPCC Guidelines*, roughly correspond to the introduction of Tier 0 and Tier 1 regulations (EPA 1998).

Step 3: Determine the Amount of CH_4 and N_2O Emitted by Vehicle, Fuel, and Control Technology Type

Emissions of CH_4 from mobile source combustion and N_2O from non-highway vehicles were calculated by multiplying emission factors in IPCC/UNEP/OECD/IEA (1997) by activity data for each vehicle type as described in Step 1 (see Table C-10 and Table C-11). The CH_4 emission factors for highway sources were derived from EPA's MOBILE5a mobile source emissions model (EPA 1997). The MOBILE5a model uses information on ambient temperature, diurnal temperature range, altitude, vehicle speeds, national vehicle registration distributions, gasoline volatility, emission control technologies, fuel composition, and the presence or absence of vehicle inspection/maintenance programs in order to produce these factors.

Emissions of N_2O—in contrast to CH_4, CO, NO_x, and NMVOCs—have not been extensively studied and are currently not well characterized. The limited number of studies that have been performed on highway vehicle emissions of N_2O have shown that emissions are generally greater from vehicles with catalytic converter systems than those without such controls, and greater from aged than from new catalysts. These systems control tailpipe emissions of NO_x (i.e., NO and NO_2) by catalytically reducing NO_x to N_2. Suboptimal catalyst performance, caused by as yet poorly understood factors, results in incomplete reduction and the conversion of some NO_x to N_2O rather than to N_2. Fortunately, newer vehicles with catalyst and engine designs meeting the more recent Tier 1 and LEV standards have shown reduced emission rates of both NO_x and N_2O.

In order to better characterize the process by which N_2O is formed by catalytic controls and to develop a more accurate national emission estimate, the EPA's Office of Mobile Sources—at its National Vehicle and Fuel Emissions Laboratory (NVFEL)—recently conducted a series of tests in order to measure emission rates of N_2O from used Tier 1 and LEV gasoline-fueled passenger cars and light-duty trucks equipped with catalytic converters. These tests and a review of the literature were used to develop the emission factors for nitrous oxide used in this inventory (EPA 1998b). The following references were used in developing the N_2O emission factors for gasoline-fueled highway passenger cars presented in Table C-10:

LEVs. Tests performed at NVFEL (EPA 1998b)[6]

Tier 1. Tests performed at NVFEL (EPA 1998b)

Tier 0. Smith and Carey (1982), Barton and Simpson (1994), and one car tested at NVFEL (EPA 1998b)

Oxidation Catalyst. Smith and Carey (1982), Urban and Garbe (1979)

Non-Catalyst. Prigent and de Soete (1989), Dasch (1992), and Urban and Garbe (1979)

Nitrous oxide emission factors for other types of gasoline-fueled vehicles—light-duty trucks, heavy-duty vehicles, and motorcycles—were estimated by adjusting the factors for gasoline passenger cars, as described above, by their relative fuel economies. This adjustment was performed using the carbon dioxide emission rates in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997) as a proxy for fuel economy (see Table C-10). Data from the literature and tests performed at NVFEL support the conclusion that light-duty trucks have higher emission rates than passenger cars. However, the use of fuel-consumption ratios to determine emission factors is considered a temporary measure only, to be replaced as soon as real data are available.

[6] It was assumed that LEVs would be operated using low-sulfur fuel (i.e., Indolene at 24 ppm sulfur). All other NVFEL tests were performed using a standard commercial fuel (CAAB at 285 ppm sulfur). Emission tests by NVFEL have consistently exhibited higher N_2O emission rates from higher sulfur fuels on Tier 1 and LEV vehicles.

The resulting N_2O emission factors employed for gasoline highway vehicles are lower than the U.S. default values presented in the *Revised 1996 IPCC Guidelines*, but are higher than the European default values, both of which were published before the more recent tests and literature review conducted by the NVFEL. The U.S. defaults in the *Guidelines* were based on three studies that tested a total of five cars using European rather than U.S. test procedures. Nitrous oxide emission factors for diesel highway vehicles were taken from the European default values found in the *Revised 1996 IPCC Guidelines* (IPCC/UNEP/OECD/IEA 1997). There is little data addressing N_2O emissions from U.S. diesel-fueled vehicles, and in general, European countries have had more experience with diesel-fueled vehicles. U.S. default values in the *Revised 1996 IPCC Guidelines* were used for non-highway vehicles.

Compared to regulated tailpipe emissions, there is relatively little data available to estimate emission factors for nitrous oxide. Nitrous oxide is not a criteria pollutant, and measurements of it in automobile exhaust have not been routinely collected. Further testing is needed to reduce the uncertainty in nitrous oxide emission factors for all classes of vehicles, using realistic driving regimes, environmental conditions, and fuels.

Estimates of NO_x, CO, and NMVOC Emissions

The emission estimates of NO_x, CO, and NMVOCs for mobile sources were taken directly from the EPA's *Draft National Air Pollutant Emissions Trends, 1900 - 1997* (EPA 1998a). This EPA report provides emission estimates for these gases by sector and fuel type using a "top down" estimating procedure whereby emissions were calculated using basic activity data, such as amount of fuel delivered or miles traveled, as indicators of emissions. Table C-12 through Table C-14 provide complete emissions estimates for 1990 through 1997.

Table C-1: Vehicle Miles Traveled for Gasoline Highway Vehicles (10^9 Miles)

Year	Passenger Cars[a]	Light-Duty Trucks[a]	Heavy-Duty Vehicles	Motorcycles	Passenger Cars (CA)[b]	Light-Duty Trucks (CA)[b]
1990	1,492.61	462.31	43.32	9.57	129.86	40.22
1991	1,512.72	468.92	43.60	9.20	131.61	40.80
1992	1,574.56	472.90	43.39	9.55	136.99	41.14
1993	1,602.28	493.20	45.96	9.89	139.40	42.91
1994	1,562.48	581.83	49.67	10.25	135.94	50.62
1995	1,605.74	597.92	51.04	10.52	139.70	52.02
1996	1,443.59	806.21	51.66	9.87	125.59	70.14
1997	1,475.85	824.31	52.89	10.10	128.40	71.71

[a] Excludes California

[b] California VMT for passenger cars and light-duty trucks was treated separately and estimated as 8.7 percent of national total.

Source: VMT data are the same as those used in EPA (1998a).

Table C-2: Vehicle Miles Traveled for Diesel Highway Vehicles (10^9 Miles)

Year	Passenger Cars	Light-Duty Trucks	Heavy-Duty Vehicles
1990	20.6	3.8	112.2
1991	20.9	3.8	112.9
1992	21.7	3.9	115.0
1993	22.1	4.1	119.6
1994	21.5	4.8	127.0
1995	22.1	4.9	130.5
1996	19.9	6.7	137.1
1997	20.4	6.8	140.5

Source: VMT data are the same as those used in EPA (1998a).

Table C-3: VMT Profile by Vehicle Age (years) and Vehicle/Fuel Type for Highway Vehicles (percent of VMT)

Vehicle Age	LDGV	LDGT	HDGV	LDDV	LDDT	HDDV	MC
1	4.9%	6.3%	2.3%	4.9%	6.3%	3.4%	14.4%
2	7.9%	8.4%	4.7%	7.9%	8.4%	6.7%	16.8%
3	8.3%	8.4%	4.7%	8.3%	8.4%	6.7%	13.5%
4	8.2%	8.4%	4.7%	8.2%	8.4%	6.7%	10.9%
5	8.4%	8.4%	4.7%	8.4%	8.4%	6.7%	8.8%
6	8.1%	6.9%	3.8%	8.1%	6.9%	7.3%	7.0%
7	7.7%	5.9%	3.3%	7.7%	5.9%	6.1%	5.6%
8	5.6%	4.4%	2.1%	5.6%	4.4%	4.0%	4.5%
9	5.0%	3.6%	2.6%	5.0%	3.6%	4.1%	3.6%
10	5.1%	3.1%	2.9%	5.1%	3.1%	5.1%	2.9%
11	5.0%	3.0%	3.4%	5.0%	3.0%	5.3%	2.3%
12	5.4%	5.3%	6.4%	5.4%	5.3%	6.6%	9.7%
13	4.7%	4.7%	5.4%	4.7%	4.7%	5.5%	0.0%
14	3.7%	4.6%	5.8%	3.7%	4.6%	5.7%	0.0%
15	2.4%	3.6%	5.1%	2.4%	3.6%	4.5%	0.0%
16	1.9%	2.8%	3.8%	1.9%	2.8%	1.9%	0.0%
17	1.4%	1.7%	4.3%	1.4%	1.7%	2.3%	0.0%
18	1.5%	2.2%	4.1%	1.5%	2.2%	2.8%	0.0%
19	1.1%	1.7%	3.5%	1.1%	1.7%	2.4%	0.0%
20	0.8%	1.4%	2.9%	0.8%	1.4%	1.6%	0.0%
21	0.6%	0.9%	2.1%	0.6%	0.9%	1.1%	0.0%
22	0.5%	0.8%	2.2%	0.5%	0.8%	0.9%	0.0%
23	0.4%	0.8%	2.2%	0.4%	0.8%	0.7%	0.0%
24	0.3%	0.5%	1.4%	0.3%	0.5%	0.5%	0.0%
25	1.0%	2.5%	11.7%	1.0%	2.5%	1.6%	0.0%

LDGV (gasoline passenger cars, also referred to as light-duty gas vehicles)
LDGT (light-duty gas trucks)
HDGV (heavy-duty gas vehicles)
LDDV (diesel passenger cars, also referred to as light-duty diesel vehicles)
LDDT (light-duty diesel trucks)
HDDV (heavy-duty diesel vehicles)
MC (motorcycles)

Table C-4: Fuel Consumption for Non-Highway Vehicles by Fuel Type (U.S. gallons)

Vehicle Type/Year	Residual	Diesel	Jet Fuel	Other
Aircraft[a]				
1990	-	-	19,138,571,644	374,401,818
1991	-	-	18,362,671,260	346,945,685
1992	-	-	17,978,360,318	341,953,660
1993	-	-	18,099,464,134	319,448,684
1994	-	-	18,885,264,653	317,309,701
1995	-	-	18,397,377,217	329,315,519
1996	-	-	19,296,093,738	310,795,109
1997	-	-	19,123,384,372	330,280,644
Ships and Boats[b]				
1990	1,666,165,227	1,943,259,570	-	1,300,400,000
1991	1,486,167,178	1,806,653,451	-	1,709,700,000
1992	2,347,064,583	1,820,275,621	-	1,316,170,000
1993	2,758,924,466	1,661,285,902	-	873,687,000
1994	2,499,868,472	1,746,597,258	-	896,700,000
1995	2,994,692,916	1,636,189,216	-	1,060,394,000
1996	2,280,373,162	1,952,357,254	-	993,671,000
1997	1,005,997,126	1,917,777,070	-	993,671,000

Vehicle Type/Year	Residual	Diesel	Jet Fuel	Other
Construction Equipment[c]				
1990	-	2,508,300,000	-	1,523,600,000
1991	-	2,447,400,000	-	1,384,900,000
1992	-	2,287,642,000	-	1,492,200,000
1993	-	2,323,183,000	-	1,270,386,667
1994	-	2,437,142,000	-	1,312,161,667
1995	-	2,273,162,000	-	1,351,642,667
1996	-	2,386,973,000	-	1,365,550,667
1997	-	2,385,236,000	-	1,365,550,667
Farm Equipment[d]				
1990	-	3,164,200,000	-	812,800,000
1991	-	3,144,200,000	-	776,200,000
1992	-	3,274,811,000	-	805,500,000
1993	-	3,077,122,000	-	845,320,000
1994	-	3,062,436,000	-	911,996,000
1995	-	3,093,224,000	-	926,732,000
1996	-	3,225,029,000	-	918,085,000
1997		3,206,359,000		918,085,000
Locomotives				
1990	25,422	3,210,111,000	-	-
1991	6,845	3,026,292,000	-	-
1992	8,343	3,217,231,000	-	-
1993	4,065	2,906,998,000	-	-
1994	5,956	3,063,441,000	-	-
1995	6,498	3,191,023,000	-	-
1996	9,309	3,266,861,000	-	-
1997	3,431	3,067,400,000	-	-

- Not applicable

[a] Other fuel aviation gasoline.

[b] Other fuel motor gasoline.

[c] Construction Equipment includes snowmobiles. Other fuel is motor gasoline.

[d] Other fuel is motor gasoline.

Table C-5: Control Technology Assignments for Gasoline Passenger Cars (percentage of VMT)*

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1
1973-1974	100%			
1975	20%	80%		
1976-1977	15%	85%		
1978-1979	10%	90%		
1980	5%	88%	7%	
1981		15%	85%	
1982		14%	86%	
1983		12%	88%	
1984-1993			100%	
1994			60%	40%
1995			20%	80%
1996				100%
1997				100%

* Excluding California VMT

Table C-6: Control Technology Assignments for Gasoline Light-Duty Trucks
(percentage of VMT)*

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1
1973-1974	100%			
1975	30%	70%		
1976	20%	80%		
1977-1978	25%	75%		
1979-1980	20%	80%		
1981		95%	5%	
1982		90%	10%	
1983		80%	20%	
1984		70%	30%	
1985		60%	40%	
1986		50%	50%	
1987-1993		5%	95%	
1994			60%	40%
1995			20%	80%
1996				100%
1997				100%

* Excluding California VMT

Table C-7: Control Technology Assignments for California Gasoline Passenger Cars and Light-Duty Trucks (percentage of VMT)

Model Years	Non-catalyst	Oxidation	Tier 0	Tier 1	LEV
1973-1974	100%				
1975-1979		100%			
1980-1981		15%	85%		
1982		14%	86%		
1983		12%	88%		
1984-1991			100%		
1992			60%	40%	
1993			20%	80%	
1994				90%	10%
1995				85%	15%
1996				80%	20%
1997				75%	25%

Table C-8: Control Technology Assignments for Gasoline Heavy-Duty Vehicles (percentage of VMT)

Model Years	Uncontrolled	Non-catalyst	Oxidation	Tier 0
#1981	100%			
1982-1984	95%		5%	
1985-1986		95%	5%	
1987		70%	15%	15%
1988-1989		60%	25%	15%
1990-1997		45%	30%	25%

Table C-9: Control Technology Assignments for Diesel Highway VMT

Vehicle Type/Control Technology	Model Years
Diesel Passenger Cars and Light-Duty Trucks	
Uncontrolled	1966-1982
Moderate control	1983-1995
Advanced control	1996-1997
Heavy-Duty Diesel Vehicles	
Uncontrolled	1966-1972
Moderate control	1983-1995
Advanced control	1996-1997
Motorcycles	
Uncontrolled	1966-1995
Non-catalyst controls	1996-1997

Table C-10: Emission Factors (g/km) for CH_4 and N_2O and "Fuel Economy" (g CO_2/km)[c] for Highway Mobile Sources

Vehicle Type/Control Technology	N_2O	CH_4	g CO_2/km
Gasoline Passenger Cars			
Low Emission Vehicles[a]	0.0176	0.025	280
Tier 1	0.0288	0.030	285
Tier 0	0.0507	0.040	298
Oxidation Catalyst	0.0322	0.070	383
Non-Catalyst	0.0103	0.120	531
Uncontrolled	0.0103	0.135	506
Gasoline Light-Duty Trucks			
Low Emission Vehicles[a]	0.0249	0.030	396
Tier 1	0.0400	0.035	396
Tier 0	0.0846	0.070	498
Oxidation Catalyst	0.0418	0.090	498
Non-Catalyst	0.0117	0.140	601
Uncontrolled	0.0118	0.135	579
Gasoline Heavy-Duty Vehicles			
Tier 0	0.1729	0.075	1,017
Oxidation Catalyst[b]	0.0870	0.090	1,036
Non-Catalyst Control	0.0256	0.125	1,320
Uncontrolled	0.0269	0.270	1,320
Diesel Passenger Cars			
Advanced	0.0100	0.01	237
Moderate	0.0100	0.01	248
Uncontrolled	0.0100	0.01	319
Diesel Light Trucks			
Advanced	0.0200	0.01	330
Moderate	0.0200	0.01	331
Uncontrolled	0.0200	0.01	415
Diesel Heavy-Duty Vehicles			
Advanced	0.0300	0.04	987
Moderate	0.0300	0.05	1,011
Uncontrolled	0.0300	0.06	1,097
Motorcycles			
Non-Catalyst Control	0.0042	0.13	219
Uncontrolled	0.0054	0.26	266

[a] Applied to California VMT only.

[b] Methane emission factor assumed based on light-duty trucks oxidation catalyst value.

[c] The carbon emission factor (g CO_2/km) was used as a proxy for fuel economy because of the greater number of significant figures compared to the km/L values presented in (IPCC/UNEP/OECD/IEA 1997).

NA (Not Available)

Table C-11: Emission Factors for CH_4 and N_2O Emissions from Non-Highway Mobile Sources (g/kg fuel)

Vehicle Type/Fuel Type	N_2O	CH_4
Ships and Boats		
Residual	0.08	0.23
Distillate	0.08	0.23
Gasoline	0.08	0.23
Locomotives		
Residual	0.08	0.25
Diesel	0.08	0.25
Coal	0.08	0.25
Farm Equipment		
Gas/Tractor	0.08	0.45
Other Gas	0.08	0.45
Diesel/Tractor	0.08	0.45
Other Diesel	0.08	0.45
Construction		
Gas Construction	0.08	0.18
Diesel Construction	0.08	0.18
Other Non-Highway		
Gas Snowmobile	0.08	0.18
Gas Small Utility	0.08	0.18
Gas HD Utility	0.08	0.18
Diesel HD Utility	0.08	0.18
Aircraft		
Jet Fuel	0.1	0.087
Aviation Gasoline	0.04	2.64

Table C-12: NO_x Emissions from Mobile Sources, 1990-1997 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997
Gasoline Highway	**4,356**	**4,654**	**4,788**	**4,913**	**5,063**	**4,804**	**4,770**	**4,629**
Passenger Cars	2,910	3,133	3,268	3,327	3,230	3,112	2,691	2,597
Light-Duty Trucks	1,140	1,215	1,230	1,289	1,503	1,378	1,769	1,725
Heavy-Duty Vehicles	296	296	280	286	318	301	298	296
Motorcycles	11	10	11	11	11	12	11	11
Diesel Highway	**2,031**	**2,035**	**1,962**	**1,900**	**1,897**	**1,839**	**1,803**	**1,753**
Passenger Cars	35	34	35	36	35	35	31	31
Light-Duty Trucks	6	7	7	7	9	9	11	11
Heavy-Duty Vehicles	1,989	1,995	1,920	1,857	1,854	1,795	1,760	1,711
Non-Highway	**3,844**	**3,869**	**3,910**	**3,936**	**3,989**	**4,089**	**4,063**	**4,137**
Ships and Boats	253	265	259	250	254	264	265	273
Locomotives	843	842	858	857	859	898	836	861
Farm Equipment	894	905	918	931	943	955	965	962
Construction Equipment	1,015	1,026	1,039	1,054	1,071	1,094	1,110	1,120
Aircraft[a]	143	141	142	142	146	150	151	161
Other[b]	697	690	695	703	716	729	736	759
Total	**10,231**	**10,558**	**10,659**	**10,749**	**10,949**	**10,732**	**10,636**	**10,519**

[a] Aircraft estimates include only emissions related to LTO cycles, and therefore do not include cruise altitude emissions.

[b] "Other" includes gasoline powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel powered recreational, industrial, lawn and garden, light construction, airport service.

Note: Totals may not sum due to independent rounding.

Table C-13: CO Emissions from Mobile Sources, 1990-1997 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997
Gasoline Highway	**51,332**	**55,104**	**53,077**	**53,375**	**54,778**	**47,767**	**46,965**	**44,225**
Passenger Cars	33,746	36,369	35,554	35,357	33,850	30,391	25,894	24,356
Light-Duty Trucks	12,534	13,621	13,215	13,786	15,739	13,453	17,483	16,659
Heavy-Duty Vehicles	4,863	4,953	4,145	4,061	5,013	3,741	3,416	3,039
Motorcycles	190	161	163	172	177	182	171	171
Diesel Highway	**1,147**	**1,210**	**1,227**	**1,240**	**1,316**	**1,318**	**1,354**	**1,368**
Passenger Cars	28	27	28	30	29	30	27	27
Light-Duty Trucks	5	5	6	6	7	7	10	10
Heavy-Duty Vehicles	1,115	1,177	1,193	1,205	1,280	1,281	1,318	1,332
Non-Highway	**13,949**	**13,942**	**14,199**	**14,359**	**14,560**	**14,761**	**14,886**	**15,201**
Ships and Boats	1,619	1,644	1,659	1,672	1,684	1,678	1,689	1,704
Locomotives	110	109	113	108	104	103	102	105
Farm Equipment	355	317	344	354	324	298	302	298
Construction Equipment	936	932	957	991	1,042	1,072	1,079	1,080
Aircraft[a]	820	806	818	821	830	855	861	918
Other[b]	10,110	10,134	10,308	10,413	10,577	10,755	10,854	11,096
Total	**66,429**	**70,256**	**68,503**	**68,974**	**70,655**	**63,846**	**63,205**	**60,794**

[a] Aircraft estimates include only emissions related to LTO cycles, and therefore do not include cruise altitude emissions.

[b] "Other" includes gasoline powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel powered recreational, industrial, lawn and garden, light construction, airport service.

Note: Totals may not sum due to independent rounding.

Table C-14: NMVOCs Emissions from Mobile Sources, 1990-1997 (Gg)

Fuel Type/Vehicle Type	1990	1991	1992	1993	1994	1995	1996	1997
Gasoline Highway	**5,444**	**5,607**	**5,220**	**5,248**	**5,507**	**4,883**	**4,743**	**4,528**
Passenger Cars	3,524	3,658	3,447	3,427	3,367	3,071	2,576	2,467
Light-Duty Trucks	1,471	1,531	1,440	1,494	1,731	1,478	1,869	1,785
Heavy-Duty Vehicles	392	384	303	296	375	297	266	243
Motorcycles	56	33	30	31	33	37	33	33
Diesel Highway	**283**	**290**	**288**	**288**	**300**	**290**	**238**	**217**
Passenger Cars	11	11	12	12	12	12	11	11
Light-Duty Trucks	2	3	3	3	4	4	5	5
Heavy-Duty Vehicles	269	276	274	273	284	274	223	201
Non-Highway	**2,225**	**2,237**	**2,266**	**2,282**	**2,303**	**2,182**	**2,175**	**2,205**
Ships and Boats	563	571	576	580	584	439	464	468
Locomotives	48	47	49	47	45	45	44	45
Farm Equipment	135	131	131	130	126	123	121	116
Construction Equipment	197	198	202	207	213	219	219	219
Aircraft[a]	163	161	162	160	159	161	161	170
Other[b]	1,120	1,129	1,146	1,160	1,175	1,196	1,167	1,186
Total	**7,952**	**8,133**	**7,774**	**7,819**	**8,110**	**7,354**	**7,156**	**6,949**

[a] Aircraft estimates include only emissions related to LTO cycles, and therefore do not include cruise altitude emissions.

[b] "Other" includes gasoline powered recreational, industrial, lawn and garden, light commercial, logging, airport service, other equipment; and diesel powered recreational, industrial, lawn and garden, light construction, airport service.

Note: Totals may not sum due to independent rounding.

Annex D
Methodology for Estimating Methane Emissions from Coal Mining

The methodology for estimating methane emissions from coal mining consists of two distinct steps. The first step addresses emissions from underground mines. For these mines, emissions were estimated on a mine-by-mine basis and then were summed to determine total emissions. The second step of the analysis involved estimating methane emissions for surface mines and post-mining activities. In contrast to the methodology for underground mines, which used mine-specific data, the methodology for estimating emissions from surface mines and post-mining activities consists of multiplying basin-specific coal production by basin-specific emissions factors.

Step 1: Estimate Methane Liberated and Methane Emitted from Underground Mines

Underground mines liberate methane from ventilation systems and from degasification systems. Some mines recover and use methane liberated from degasification systems, thereby reducing methane emissions to the atmosphere. Total methane emitted from underground mines equals methane liberated from ventilation systems, plus methane liberated from degasification systems, minus methane recovered and used.

Step 1.1 Estimate Methane Liberated from Ventilation Systems

All coal mines with detectable methane emissions[7] use ventilation systems to ensure that methane levels remain within safe concentrations. Many coal mines do not have detectable methane emissions, while others emit several million cubic feet per day (MMCFD) from their ventilation systems. On a quarterly basis, the U.S. Mine Safety and Health Administration (MSHA) measures methane emissions levels at underground mines. MSHA maintains a database of measurement data from all underground mines with detectable levels of methane in their ventilation air. Based on the four quarterly measurements, MSHA estimates average daily methane liberated at each of the underground mines with detectable emissions.

For the years 1990 through 1996, EPA obtained MSHA emissions data for a large but incomplete subset of all mines with detectable emissions. This subset includes mines emitting at least 0.1 MMCFD for some years and at least 0.5 MMCFD for other years, as shown in Table D-1. Well over 90 percent of all ventilation emissions are concentrated in these subsets. For 1997, EPA obtained the complete MSHA database for all 586 mines with detectable methane emissions. These mines were assumed to account for 100 percent of methane liberated from underground mines.

Using this complete 1997 database, the portion of total emissions accounted for by mines emitting more and less than 0.1 MMCFD or 0.5 MMCFD was estimated (see Table D-1). These proportions were then applied to the years 1990 through 1996 to account for the less than 10 percent of ventilation emissions not accounted for by mines without MSHA data.

Average daily methane emissions were multiplied by 365 days per year to determine annual emissions for each mine. Total ventilation emissions for a particular year was estimated by summing emissions from individual mines.

[7] MSHA records coal mine methane readings with concentrations of greater than 50 ppm (parts per million) methane. Readings below this threshold are considered non-detectable.

Table D-1: Mine-Specific Data Used to Estimate Ventilation Emissions

Year	Individual Mine Data Used
1990	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1991	1990 Emissions Factors Used Instead of Mine-Specific Data
1992	1990 Emissions Factors Used Instead of Mine-Specific Data
1993	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1994	All Mines Emitting at Least 0.1 MMCFD (Assumed to Account for 97.8% of Total)*
1995	All Mines Emitting at Least 0.5 MMCFD (Assumed to Account for 94.1% of Total)*
1996	All Mines Emitting at Least 0.5 MMCFD (Assumed to Account for 94.1% of Total)*
1997	All Mines with Detectable Emissions (Assumed to Account for 100% of Total)

* Factor derived from a complete set of individual mine data collected for 1997.

Step 1.2 Estimate Methane Liberated from Degasification Systems

In 1997, twenty-four coal mines use degasification systems in addition to their ventilation systems for methane control. Coal mines use several different types of degasification systems to remove methane, including vertical wells and horizontal boreholes to recover methane prior to mining of the coal seam. Gob wells and cross-measure boreholes recover methane from the overburden (i.e., GOB area) after mining of the seam (primarily in longwall mines).

MSHA collects information about the presence and type of degasification systems in some mines, but does not collect quantitative data on the amount of methane liberated. Thus, the methodology estimated degasification emissions on a mine-by-mine basis based on other sources of available data. Many of the coal mines employing degasification systems have provided EPA with information regarding methane liberated from their degasification systems. For these mines, this reported information was used as the estimate. In other cases in which mines sell methane recovered from degasification systems to a pipeline, gas sales were used to estimate methane liberated from degasification systems (see Step 1.3). Finally, for those mines that do not sell methane to a pipeline and have not provided information to EPA, methane liberated from degasification systems was estimated based on the type of system employed. For example, for coal mines employing gob wells and horizontal boreholes, the methodology assumes that degasification emissions account for 40 percent of total methane liberated from the mine.

Step 1.3: Estimate Methane Recovered from Degasification Systems and Used (Emissions Avoided)

In 1997, fourteen active coal mines had developed methane recovery and use projects and sold the recovered methane to a pipeline. One coal mine also used some recovered methane in a thermal dryer in addition to selling gas to a pipeline. Where available, state agency gas sales data were used to estimate emissions avoided for these projects. Emissions avoided were attributed to the year in which the coal seam was mined. For example, if a coal mine recovered and sold methane using a vertical well drilled five years in advance of mining, the emissions avoided associated with those gas sales were attributed to the year during which the well was mined-through (five years after the gas was sold). In order to estimate emissions avoided for those coal mines using degasification methods that recover methane in advance of mining, information was needed regarding the amount of gas recovered and the number of years in advance of mining that wells were drilled. In most cases, coal mine operators provided EPA with this information, which was then used to estimate emissions avoided for a particular year. Additionally, several state agencies made production data available for individual wells. For some mines, these individual well data were used to assign gas sales from individual wells to the appropriate emissions avoided year.

Step 2: Estimate Methane Emitted from Surface Mines and Post-Mining Activities

Mine-specific data were not available for estimating methane emissions from surface coal mines or for post-mining activities. For surface mines and post-mining activities, basin-specific coal production was multiplied by a basin-specific emission factor to determine methane emissions.

Step 2.1: Define the Geographic Resolution of the Analysis and Collect Coal Production Data

The first step in estimating methane emissions from surface mining and post-mining activities was to define the geographic resolution of the analysis and to collect coal production data at that level of resolution. The U.S. analysis was conducted by coal basin as defined in Table D-2. Table D-2 presents coal basin definitions by basin and by state.

The Energy Information Agency (EIA) Coal Industry Annual reports state- and county-specific underground and surface coal production by year. To calculate production by basin, the state level data were grouped into coal basins using the basin definitions listed in Table D-2. For two states—West Virginia and Kentucky—county-level production data was used for the basin assignments because coal production occurred from geologically distinct coal basins within these states. Table D-3 presents the coal production data aggregated by basin.

Step 2.2: Estimate Emissions Factors for Each Emissions Type

Emission factors for surface mined coal were developed from the *in situ* methane content of the surface coal in each basin. Based on an analysis presented in EPA (1993), surface mining emission factors were estimated to be from 1 to 3 times the average *in situ* methane content in the basin. For this analysis, the surface mining emission factor was determined to be twice the *in situ* methane content in the basin. Furthermore, the post-mining emission factors used were estimated to be 25 to 40 percent of the average *in situ* methane content in the basin. For this analysis, the post-mining emission factor was determined to be 32.5 percent of the *in situ* methane content in the basin. Table D-4 presents the average *in situ* content for each basin, along with the resulting emission factor estimates.

Step 2.3: Estimate Methane Emitted

The total amount of methane emitted was calculated by multiplying the coal production in each basin by the appropriate emission factors.

Total annual methane emissions is equal to the sum of underground mine emissions plus surface mine emissions plus post-mining emissions. Table D-5 and Table D-6 present estimates of methane liberated, methane used, and methane emissions for 1990 through 1997. Table D-7 provides methane emissions by state.

Table D-2: Coal Basin Definitions by Basin and by State

Basin	States
Northern Appalachian Basin	Maryland, Ohio, Pennsylvania, West VA North
Central Appalachian Basin	Kentucky East, Tennessee, Virginia, West VA South
Warrior Basin	Alabama
Illinois Basin	Illinois, Indiana, Kentucky West
South West and Rockies Basin	Arizona, California, Colorado, New Mexico, Utah
North Great Plains Basin	Montana, North Dakota, Wyoming
West Interior Basin	Arkansas, Iowa, Kansas, Louisiana, Missouri, Oklahoma, Texas
Northwest Basin	Alaska, Washington
State	**Basin**
Alabama	Warrior Basin
Alaska	Northwest Basin
Arizona	South West And Rockies Basin
Arkansas	West Interior Basin
California	South West And Rockies Basin
Colorado	South West And Rockies Basin
Illinois	Illinois Basin
Indiana	Illinois Basin
Iowa	West Interior Basin
Kansas	West Interior Basin
Kentucky East	Central Appalachian Basin
Kentucky West	Illinois Basin
Louisiana	West Interior Basin
Maryland	Northern Appalachian Basin
Missouri	West Interior Basin
Montana	North Great Plains Basin
New Mexico	South West And Rockies Basin
North Dakota	North Great Plains Basin
Ohio	Northern Appalachian Basin
Oklahoma	West Interior Basin
Pennsylvania.	Northern Appalachian Basin
Tennessee	Central Appalachian Basin
Texas	West Interior Basin
Utah	South West And Rockies Basin
Virginia	Central Appalachian Basin
Washington	Northwest Basin
West Virginia South	Central Appalachian Basin
West Virginia North	Northern Appalachian Basin
Wyoming	North Great Plains Basin

Table D-3: Annual Coal Production (thousand short tons)

Underground Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997
Northern Appalachia	103,865	103,450	105,220	77,032	100,122	98,103	106,729	112,135
Central Appalachia	198,412	181,873	177,777	164,845	170,893	166,495	171,845	177,720
Warrior	17,531	17,062	15,944	15,557	14,471	17,605	18,217	18,505
Illinois	69,167	69,947	73,154	55,967	69,050	69,009	67,046	64,728
S. West/Rockies	32,754	31,568	31,670	35,409	41,681	42,994	43,088	44,503
N. Great Plains	1,722	2,418	2,511	2,146	2,738	2,018	2,788	2,854
West Interior	105	26	59	100	147	25	137	212
Northwest	0	0	0	0	0	0	0	0
Total	**423,556**	**406,344**	**406,335**	**351,056**	**399,102**	**396,249**	**409,850**	**420,657**

Surface Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997
Northern Appalachia	60,761	51,124	50,512	48,641	44,960	39,372	39,788	40,179
Central Appalachia	94,343	91,785	95,163	94,433	106,129	106,250	108,869	113,275
Warrior	11,413	10,104	9,775	9,211	8,795	7,036	6,420	5,963
Illinois	72,000	63,483	58,814	50,535	51,868	40,376	44,754	46,862
S. West/Rockies	43,863	42,985	46,052	48,765	49,119	46,643	43,814	48,374
N. Great Plains	249,356	259,194	258,281	275,873	308,279	331,367	343,404	349,612
West Interior	64,310	61,889	63,562	60,574	58,791	59,116	60,912	59,061
Northwest	6,707	6,579	6,785	6,340	6,460	6,566	6,046	5,945
Total	**602,753**	**587,143**	**588,944**	**594,372**	**634,401**	**636,726**	**654,007**	**669,271**

Total Coal Production

Basin	1990	1991	1992	1993	1994	1995	1996	1997
Northern Appalachia	164,626	154,574	155,732	125,673	145,082	137,475	146,517	152,314
Central Appalachia	292,755	273,658	272,940	259,278	277,022	272,745	280,714	290,995
Warrior	28,944	27,166	25,719	24,768	23,266	24,641	24,637	24,468
Illinois	141,167	133,430	131,968	106,502	120,918	109,385	111,800	111,590
S. West/Rockies	76,617	74,553	77,722	84,174	90,800	89,637	86,902	92,877
N. Great Plains	251,078	261,612	260,792	278,019	311,017	333,385	346,192	352,466
West Interior	64,415	61,915	63,621	60,674	58,938	59,141	61,049	59,273
Northwest	6,707	6,579	6,785	6,340	6,460	6,566	6,046	5,945
Total	**1,026,309**	**993,487**	**995,279**	**945,428**	**1,033,503**	**1,032,975**	**1,063,857**	**1,0829,928**

Source: EIA (1990-97), Coal Industry Annual. U.S. Department of Energy, Washington, D.C., Table 3.
Note: Totals may not sum due to independent rounding.

Table D-4: Coal Surface and Post-Mining Methane Emission Factors (ft^3 per short ton)

Basin	Surface Average *in situ* Content	Underground Average *in situ* Content	Surface Mine Factors	Post-Mining Surface Factors	Post Mining Underground
Northern Appalachia	49.3	171.7	98.6	16.0	16.0
Central Appalachia	49.3	330.7	98.6	16.0	16.0
Warrior	49.3	318.0	98.6	16.0	16.0
Illinois	39.0	57.20	78.0	12.7	12.7
S. West/Rockies	15.3	225.8	30.6	5.0	5.0
N. Great Plains	3.2	41.67	6.4	1.0	1.0
West Interior	3.2	41.67	6.4	1.0	1.0
Northwest	3.2	41.67	6.4	1.0	1.0

Source: EPA (1993), Anthropogenic Methane Emissions in the United States: Estimates for 1990, Report to Congress, U.S. Environmental Protection Agency, Air and Radiation, April.

Table D-5: Underground Coal Mining Methane Emissions (billion cubic feet)

Activity	1990	1991	1992	1993	1994	1995	1996	1997
Ventilation Output	112	NA	NA	95	96	102	90	96
Adjustment Factor for Mine Data[a]	97.8%	NA	NA	97.8%	97.8%	91.4%	91.4%	100.0%
Ventilation Liberated	114	NA	NA	97	98	111	99	96
Degasification System Liberated	57	NA	NA	49	50	50	51	57
Total Underground Liberated	171	164	162	146	149	161	150	153
Recovered & Used	(15)	(15)	(19)	(24)	(29)	(31)	(35)	(42)
Total	**156**	**149**	**142**	**121**	**119**	**130**	**115**	**112**

[a] Refer to Table D-1

Note: Totals may not sum due to independent rounding.

Table D-6: Total Coal Mining Methane Emissions (billion cubic feet)

Activity	1990	1991	1992	1993	1994	1995	1996	1997
Underground Mining	156	149	142	121	119	130	115	112
Surface Mining	25	23	23	23	24	22	23	24
Post-Mining (Underground)	33	31	30	27	30	30	31	31
Post-Mining (Surface)	4	4	4	4	4	4	4	4
Total	**218**	**207**	**200**	**175**	**177**	**185**	**172**	**171**

Note: Totals may not sum due to independent rounding.

Table D-7: Total Coal Mining Methane Emissions by State (million cubic feet)

State	1990	1993	1994	1995	1996	1997
Alabama	33,650	27,000	30,713	39,945	30,808	26,722
Alaska	13	12	12	13	11	11
Arizona	402	433	464	425	371	417
Arkansas	0	0	0	0	0	0
California	2	0	0	0	0	0
Colorado	10,117	7,038	9,029	8,541	5,795	9,057
Illinois	10,643	8,737	10,624	11,106	10,890	8,571
Indiana	3,149	2,623	2,791	2,106	2,480	3,088
Iowa	3	1	0	0	0	0
Kansas	5	3	2	2	2	3
Kentucky	21,229	19,823	21,037	19,103	18,292	20,089
Louisiana	24	23	26	28	24	26
Maryland	510	245	256	259	287	296
Missouri	20	5	6	4	5	3
Montana	280	267	310	294	283	305
New Mexico	905	1,186	1,223	980	856	961
North Dakota	217	238	240	224	222	220
Ohio	4,710	4,110	4,377	3,900	3,992	4,313
Oklahoma	13	14	52	14	14	132
Pennsylvania	22,573	26,437	24,026	27,086	26,567	30,339
Tennessee	800	350	338	366	418	390
Texas	415	406	389	392	410	397
Utah	4,562	4,512	3,696	3,541	4,061	4,807
Virginia	45,883	30,454	26,782	19,898	19,857	16,990
Washington	37	35	36	36	34	33
West Virginia	56,636	39,477	38,565	44,894	44,380	41,454
Wyoming	1,382	1,578	1,782	1,977	2,090	2,122
Total	**218,180**	**175,007**	**176,781**	**185,134**	**172,149**	**170,746**

Note: The emission estimates provided above are inclusive of emissions from underground mines, surface mines and post-mining activities. The following states have neither underground nor surface mining and thus report no emissions as a result of coal mining: Connecticut, Delaware, Florida, Georgia, Hawaii, Idaho, Maine, Massachusetts, Michigan, Minnesota, Mississippi, Nebraska, Nevada, New Hampshire, New Jersey, New York, North Carolina, Oregon, Rhode Island, South Carolina, South Dakota, Vermont, and Wisconsin. Emission estimates are not given for 1991 and 1992 because underground mine data was not available for those years.

Annex E

Methodology for Estimating Methane Emissions from Natural Gas Systems

The following steps were used to estimate methane emissions from natural gas systems.

Step 1: Calculate Emission Estimates for Base Year 1992 Using GRI/EPA Study

The first step in estimating methane emissions from natural gas systems was to develop a detailed base year estimate of emissions. The study by GRI/EPA (1996) divides the industry into four stages to construct a detailed emissions inventory for the year 1992. These stages include: field production, processing, transmission and storage (both underground and liquefied gas storage), and distribution. This study produced emission factors and activity data for over 100 different emission sources within the natural gas system. Emissions for 1992 were estimated by multiplying activity levels by emission factors for each system component and then summing by stage. Since publication, EPA has updated activity data for some of the components in the system. Table E-1 displays the 1992 GRI/EPA activity levels and emission factors for venting and flaring from the field production stage, and the current EPA activity levels and emission factors. The data in Table E-1 is a representative sample of data used to calculate emissions from all stages.

Step 2: Collect Aggregate Statistics on Main Driver Variables

As detailed data on each of the over 100 sources were not available for the period 1990 through 1997, activity levels were estimated using aggregate statistics on key drivers, including: number of producing wells (IPAA 1997), number of gas plants (AGA 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997), miles of transmission pipeline (AGA, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997), miles of distribution pipeline (AGA 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997), miles of distribution services (AGA 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997), and energy consumption (EIA 1997a). Data on the distribution of gas mains by material type was not available for certain years from AGA. For those years, the average distribution by type was held constant. Table E-2 provides the activity levels of some of the key drivers in the natural gas analysis.

Step 3: Estimate Emission Factor Changes Over Time

For the period 1990 through 1995, the emission factors were held constant, based on 1992 values. An assumed improvement in technology and practices was estimated to reduce emission factors by 5 percent by the year 2020. This assumption, annualized, amounts to a 0.2 and 0.4 percent decline in the 1996 and 1997 emission factors, respectively.

Step 4: Estimate Emissions for Each Source

Emissions were estimated by multiplying the activity levels by emission factors. Table E-3 provides emission estimates for venting and flaring emissions from the field production stage.

Table E-1: 1992 Data and Emissions (Mg) for Venting and Flaring from Natural Gas Field Production Stage

Activity	GRI/EPA Values			EPA Adjusted Values		
	Activity Data	Emission Factor	Emissions	Activity Data	Emission Factor	Emissions
Drilling and Well Completion						
Completion Flaring	844 compl/yr	733 scf/comp	11.9	400 compl/yr	733 scf/comp	5.63
Normal Operations						
Pneumatic Device Vents	249,111 controllers	345 scfd/device	602,291	249,111 controllers	345 scfd/device	602,291
Chemical Injection Pumps	16,971 active pumps	248 scfd/pump	29,501	16,971 active pumps	248 scfd/pump	29,502
Kimray Pumps	11,050,000 MMscf/yr	368 scf/MMscf	78,024	7,380,194 MMscf/yr	992 scf/MMscf	140,566
Dehydrator Vents	12,400,000 MMscf/yr	276 scf/MMscf	65,608	8,200,215 MMscf/yr	276 scf/MMscf	43,387
Compressor Exhaust Vented						
Gas Engines	27,460 MMHPhr	0.24 scf/HPhr	126,536	27,460 MMHPhr	0.24 scf/HPhr	126,535
Routine Maintenance						
Well Workovers						
Gas Wells	9,392 w.o./yr	2,454 scfy/w.o.	443	9,392 w.o./yr	2,454 scfy/w.o.	443
Well Clean Ups (LP Gas Wells)	114,139 LP gas wells	49,570 scfy/LP well	108,631	114,139 LP gas wells	49,570 scfy/LP well	108,631
Blowdowns						
Vessel BD	255,996 vessels	78 scfy/vessel	383	242,306 vessels	78 scfy/vessel	363
Pipeline BD	340,000 miles (gath)	309 scfy/mile	2,017	340,200 miles (gath)	309 scfy/mile	2,018
Compressor BD	17,112 compressors	3,774 scfy/comp	1,240	17,112 compressors	3,774 scfy/comp	1,240
Compressor Starts	17,112 compressors	8,443 scfy/comp	2,774	17,112 compressors	8,443 scfy/comp	2,774
Upsets						
Pressure Relief Valves	529,440 PRV	34.0 scfy/PRV	346	529,440 PRV	34.0 scfy/PRV	346
ESD	1,115 platforms	256,888 scfy/plat	5,499	1,372 platforms	256,888 scfy/plat	6,767
Mishaps	340,000 miles	669 scfy/mile	4,367	340,200 miles	669 scfy/mile	4,370

Table E-2: Activity Factors for Key Drivers

Variable	Unit	1990	1991	1992	1993	1994	1995	1996	1997
Transmission Pipelines Length	miles	280,100	281,600	284,500	269,600	268,300	264,900	257,000	257,000
Wells									
GSAM Appalachia Wells [a]	# wells	120,162	121,586	123,685	124,708	122,021	123,092	122,700	122,700
GSAM N Central Associated Wells [a]	# wells	3,862	3,890	3,852	3,771	3,708	3,694	3,459	3,459
GSAM N Central Non-Associated Wells [a]	# wells	3,105	3,684	4,317	4,885	5,813	6,323	7,073	7,073
GSAM Rest of US Wells [a]	# wells	145,100	147,271	152,897	156,568	160,011	164,750	173,928	173,928
GSAM Rest of US Associated Wells [a]	# wells	256,918	262,441	253,587	249,265	248,582	245,338	246,598	246,598
Appalch. + N. Central Non-Assoc. + Rest of US	# wells	268,367	272,541	280,899	286,161	287,845	294,165	303,701	303,701
Platforms									
Gulf of Mexico Off-shore Platforms	# platforms	3,798	3,834	3,800	3,731	3,806	3,868	3,846	3,846
Rest of U.S. (offshore platforms)	# platforms	24	24	24	24	23	23	24	23
N. Central Non-Assoc. + Rest of US Wells	# platforms	148,205	150,955	157,214	161,453	165,824	171,073	181,001	181,001
Gas Plants									
Number of Gas Plants	# gas plants	761	734	732	726	725	675	623	615
Distribution Services									
Steel - Unprotected	# of services	5,500,993	5,473,625	5,446,393	5,419,161	5,392,065	5,365,105	5,388,279	5,388,279
Steel - Protected	# of services	19,916,202	20,352,983	20,352,983	20,512,366	20,968,447	21,106,562	21,302,429	21,302,429
Plastic	# of services	16,269,414	17,654,006	17,681,238	18,231,903	19,772,041	20,270,203	20,970,924	20,970,924
Copper	# of services	228,240	233,246	233,246	235,073	240,299	241,882	244,127	244,127
Total	# of services	41,914,849	43,713,860	43,713,860	44,398,503	46,372,852	46,983,752	47,905,759	47,905,759
Distribution Mains									
Steel - Unprotected	miles	91,267	90,813	90,361	89,909	89,460	89,012	88,567	88,567
Steel - Protected	miles	491,120	492,887	496,839	501,480	497,051	499,488	468,833	468,833
Cast Iron	miles	52,644	52,100	51,800	50,086	48,542	48,100	47,100	47,100
Plastic	miles	202,269	221,600	244,300	266,826	284,247	294,400	329,700	329,700
Total	miles	837,300	857,400	883,300	908,300	919,300	931,000	934,200	934,200

[a] GSAM is the Gas Systems Analysis Model (GSAM 1997) of the Federal Energy Technology Center of the U.S. Department of Energy. It is a supply, demand and transportation model.

Table E-3: CH_4 Emission Estimates for Venting and Flaring from the Field Production Stage (Mg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997
Drilling and Well Completion								
Completion Flaring	5.4	5.5	5.6	5.7	5.8	5.9	6.1	6.1
Normal Operations								
Pneumatic Device Vents	567,778	578,313	602,291	618,531	635,276	655,386	691,999	691,999
Chemical Injection Pumps	36,449	37,323	39,053	40,277	41,668	43,111	45,664	45,664
Kimray Pumps	134,247	136,380	140,566	143,211	144,040	147,191	151,565	151,565
Dehydrator Vents	41,436	42,095	43,387	44,203	44,459	45,432	46,782	46,782
Compressor Exhaust Vented								
Gas Engines	119,284	121,498	126,535	129,947	133,465	137,690	145,382	145,382
Routine Maintenance								
Well Workovers								
Gas Wells	531	540	556	567	570	582	600	600
Well Clean Ups (LP Gas Wells)	101,118	102,725	105,878	107,870	108,494	110,868	114,162	114,162
Blowdowns								
Vessel BD	256	261	271	278	284	292	306	306
Pipeline BD	1,710	1,729	1,772	1,772	1,818	1,852	1,908	1,908
Compressor BD	1,548	1,573	1,627	1,662	1,687	1,730	1,802	1,802
Compressor Starts	3,462	3,518	3,640	3,718	3,773	3,871	4,031	4,031
Upsets								
Pressure Relief Valves	326	332	346	355	365	376	397	397
ESD	6,764	6,827	6,767	6,646	6,773	6,882	6,834	6,829
Mishaps	925	936	959	974	984	1,003	1,033	1,033

Annex F

Methodology for Estimating Methane Emissions from Petroleum Systems

The methodology for estimating methane emissions from petroleum systems is being updated. EPA anticipates that current methodology understates emissions, and that the new methodology will be incorporated into future inventories. The following steps, however, were used to estimate methane emissions from petroleum systems for this report.

Step 1: Production Field Operations

The American Petroleum Institute (API) publishes active oil well data in reports such as the *API Basic Petroleum Data Book*. To estimate activity data, the percentage of oil wells that were not associated with natural gas production (an average of 56.4 percent from 1990 through 1997) was multiplied by the total number of wells in the United States. This number was then multiplied by per well emission factors for fugitive emissions and routine maintenance from Tilkicioglu & Winters (1989). Table F-1 displays the activity data, emission factors, and emissions estimates used.

Step 2: Crude Oil Storage

Methane emissions from storage were calculated as a function of annual U.S. crude stocks less strategic petroleum stocks for each year, obtained from annual editions of the *Petroleum Supply Annual published by the* Energy Information Administration (EAI 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998). These stocks were multiplied by emission factors from Tilkicioglu & Winters (1989) to estimate emissions. Table F-2 displays the activity data, emission factors, and emissions estimates used.

Step 3: Refining

Methane emissions from refinery operations were based on U.S. refinery working storage capacity. The EIA reports this data every two years. The data was last reported in 1997 for the 1996 estimates. Consequently, 1997 data for total U.S. refinery working storage capacity were not available. These estimates were derived using the average of the percent difference each year from 1990 through 1996 (EIA 1990, 1991, 1992, 1993, 1994, 1995, 1997). This capacity was multiplied by an emission factor from Tilkicioglu & Winters (1989) to estimate emissions. Table F-3 provides the activity data, emission factors, and emissions estimates used.

Step 4: Tanker Operations

Methane emissions from the transportation of petroleum on marine vessels were estimated using activity data on crude oil imports, U.S. crude oil production, Alaskan crude oil production, and Alaskan refinery crude oil capacity. All activity data, excluding the Alaskan refinery crude oil capacity estimates, were taken from annual editions of the *Petroleum Supply Annual* (EIA 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998). The capacity estimates are reported every two years but were not reported for 1997. The data were derived using the average of the percent difference in Alaskan refinery crude oil capacity each year from 1990 through 1996 (EIA 1990, 1991, 1992, 1993, 1994, 1995, 1997).

Tilkicioglu & Winters (1989) identified three sources of emissions in the transportation of petroleum. These are emissions from loading Alaskan crude oil onto tankers, emissions from crude oil transfers to terminals, and ballast emissions.

Step 4.1: Loading Alaskan Crude Oil onto Tankers

The net amount of crude oil transported by tankers was determined by subtracting Alaskan refinery capacity from Alaskan crude oil production. This net amount was multiplied by an emission factor from Tilkicioglu & Winters (1989) to estimate emissions. The activity data and emissions estimates are shown in Table F-4.

Step 4.2: Crude Oil Transfers to Terminals

Methane emissions from crude oil transfers were taken from the total domestic crude oil transferred to terminals. This amount was assumed to be 10 percent of total domestic crude oil production less Alaskan crude oil production. To estimate emissions, this transferred amount was multiplied by an emission factor from Tilkicioglu & Winters (1989). The activity data and emissions estimates are shown in Table F-5.

Step 4.3: Ballast Emissions

Ballast emissions are emitted from crude oil transported on marine vessels. This amount was calculated from the sum of Alaskan crude oil on tankers, the amount of crude oil transferred to terminals, and all crude oil imports less Canadian imports. Ballast volume was assumed to be 17 percent of this sum (Tilkicioglu & Winters 1989). This amount was then multiplied by an emission factor to estimate emissions. The activity data and emissions estimates are shown in Table F-6.

Total emissions from tanker operations are shown in Table F-7.

Step 5: Venting and Flaring

Methane emissions from venting and flaring were based on 1990 emissions estimates from EPA (1993) and were held constant through 1997 due to the lack of data available to assess the change in emissions.

Table F-1: CH_4 Emissions from Petroleum Production Field Operations

Variable	Units	1990	1991	1992	1993	1994	1995	1996	1997
Total Oil Wells		587,762	610,204	594,189	583,879	581,657	574,483	574,419	573,504
% Not Assoc. w/ Natural Gas	%	55.6%	56.4%	56.7%	56.7%	56.6%	56.7%	56.5%	56.5%
Oil Wells in Analysis		326,982	343,873	336,749	330,843	329,366	325,451	324,362	323,883
Emission Factors									
Fugitive	kg/well/yr	72							
Routine Maintenance	kg/well/yr	0.15							
Emissions									
Fugitive	mill kg/yr	23.5	24.8	24.3	23.9	23.7	23.4	23.4	23.3
Routine Maintenance	mill kg/yr	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table F-2: CH_4 Emissions from Petroleum Storage

Variable	Units	1990	1991	1992	1993	1994	1995	1996	1997
Total Crude Stocks	1000 barrels/yr	908,387	893,102	892,864	922,465	928,915	894,968	849,669	868,11
Strategic Petroleum Stocks	1000 barrels/yr	585,692	568,508	574,724	587,080	591,670	591,640	566,000	563,429
Crude Oil Storage	1000 barrels/yr	322,695	324,594	318,140	335,385	337,245	303,328	283,669	304,609
Emission Factors									
Breathing	kg CH_4/brl/yr	0.002612							
Working	kg CH_4/brl/yr	0.002912							
Fugitive	kg CH_4/brl/yr	4.99×10^{-5}							
Emissions									
Breathing	kg/yr	842,892	847,853	830,994	876,039	880,897	792,305	740,955	795,862
Working	kg/yr	939,602	945,131	926,339	976,552	981,968	883,210	825,969	887,176
Fugitive	kg/yr	16,118	16,213	15,891	16,752	16,845	15,151	14,169	15,219
Total Emissions	**mill. kg/yr**	**1.80**	**1.81**	**1.77**	**1.87**	**1.88**	**1.69**	**1.58**	**1.70**

Table F-3: CH_4 Emissions from Petroleum Refining

Variable (Jan 1)	Units	1990	1991	1992	1993	1994	1995	1996	1997
Refinery Storage Capacity	1000 barrels/yr	174,490	171,366	167,736	170,823	164,364	161,305	158,435	155,929
Storage Emission Factor	Mg CH_4/brl/yr	5.9×10^{-5}							
Emissions	mill. kg/yr	10.29	10.10	9.89	10.07	9.69	9.51	9.34	9.19

Table F-4: CH_4 Emissions from Petroleum Transportation: Loading Alaskan Crude Oil onto Tankers (Barrels/day)*

Variable	1990	1991	1992	1993	1994	1995	1996	1997
Alaskan Crude	1,773,452	1,798,216	1,718,690	1,582,175	1,558,762	1,484,000	1,393,000	1,296,000
Alaskan Refinery Crude Capacity	229,850	239,540	222,500	256,300	261,000	275,152	283,350	293,989
Net Tankered	1,543,602	1,558,676	1,496,190	1,325,875	1,297,762	1,208,848	1,109,650	1,002,011
Conversion Factor (gal oil/ barrel oil)	42							
Emission factor (lbs/gallon)	0.001							
Emissions @ Loading AK (lbs/day)	64,831	65,464	62,840	55,687	54,506	50,772	46,605	42,084
Methane Content of Gas (%)	20.80%							
Emissions @ Loading AK (mill kg/yr)	2.23	2.26	2.17	1.92	1.88	1.75	1.61	1.45

* Unless otherwise noted

Table F-5: CH_4 Emissions from Petroleum Transportation: Crude Oil Transfers to Terminals (Barrels/day)*

Variable	1990	1991	1992	1993	1994	1995	1996	1997
US Crude Production	7,355,307	7,416,545	7,190,773	6,846,666	6,661,578	6,560,000	6,465,000	6,452,000
AK Crude Production	1,773,452	1,798,216	1,718,690	1,582,175	1,558,762	1,484,000	1,393,000	1,296,000
US Crude - AK Crude	5,581,855	5,618,329	5,472,082	5,264,490	5,102,816	5,076,000	5,072,000	5,156,000
10% transported to terminals	558,185	561,833	547,208	526,449	510,282	507,600	507,200	515,600
Conversion Factor (gal oil/ barrel oil)	42							
Emission factor (lbs/gallon)	0.001							
Emissions from Transfers (lbs/day)	23,444	23,597	22,983	22,111	21,432	21,319	21,302	21,655
Methane Content of Gas (%)	20.80%							
Emissions from Transfers (mill kg/yr)	0.81	0.81	0.79	0.76	0.74	0.73	0.73	0.75

* Unless otherwise noted

Table F-6: CH_4 Emissions from Petroleum Transportation: Ballast Emissions (Barrels/day)*

Variable	1990	1991	1992	1993	1994	1995	1996	1997
Crude Imports (less Canadian)	5,251,701	5,038,786	5,300,616	5,886,921	6,079,773	6,125,482	6,909,429	7,787,604
Alaskan Crude (Net Tankered)	1,543,602	1,558,676	1,496,190	1,325,875	1,297,762	1,208,848	1,109,650	1,002,011
10% Crude Prod. Transported to terminals	558,185	561,833	547,208	526,449	510,282	507,600	507,200	515,600
Conversion Factor (gal oil/ barrel oil)	42							
Emission factor (lbs/1000 gallons)	1.4							
Crude Oil Unloaded	7,353,489	7,159,296	7,344,015	7,739,245	7,887,816	7,841,930	8,526,279	9,305,215
Ballast Volume (17% of Crude Unloaded)	1,250,093	1,217,080	1,248,483	1,315,672	1,340,929	1,333,128	1,449,467	1,581,887
Ballast Emissions (lbs/day)	73,505	71,564	73,411	77,361	78,847	78,388	85,229	93,015
Methane Content of Gas (%)	20.80%							
Ballast Emissions (mill kg/yr)	2.53	2.47	2.53	2.67	2.72	2.70	2.94	3.20

* Unless otherwise noted

Table F-7: Total CH_4 Emissions from Petroleum Transportation

Year	Million kg/yr
1990	5.6
1991	5.5
1992	5.5
1993	5.4
1994	5.3
1995	5.2
1996	5.3
1997	5.4

Annex G
Methodology for Estimating Methane Emissions from Enteric Fermentation

The following steps were used to estimate methane emissions from enteric fermentation in livestock.

Step 1: Collect Livestock Population Data

All livestock population data, except for horses, was taken from U.S. Department of Agriculture (USDA) statistical reports. For each animal category, the USDA publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revision to earlier published data. Recent reports were obtained from the USDA Economics and Statistics System website, at <http://www.mannlib.cornell.edu/usda/>, while historical data were downloaded from the USDA-National Agricultural Statistics Service (NASS) website at <http://www.usda.gov/nass/pubs/dataprd1.htm>.

The Food and Agriculture Organization (FAO) publish horse population data. These data were accessed from the FAOSTAT database at <http://apps.fao.org/>. Table G-1 summarizes the published population data by animal type.

Step 2: Estimate Emission Factors for Dairy Cows

Regional dairy cow emission factors from the 1993 Report to Congress (EPA 1993) were used as the starting point for the analysis. These emission factors were used to calibrate a model of methane emissions from dairy cows. The model applies revised regional emission factors that reflect changes in milk production per cow over time. Increases in milk production per cow, in theory, require increases in feed intake, which lead to higher methane emissions per cow. Table G-2 presents the emission factors per head by region used for dairy cows and milk production. The regional definitions are from EPA (1993).

Step 3: Estimate Methane Emissions from Dairy Cattle

Dairy cow emissions for each state were estimated by multiplying the published state populations by the regional emission factors, as calculated in Step 2. Dairy replacement emissions were estimated by multiplying national replacement populations by a national emission factor. The USDA reported the number of replacements 12 to 24 months old as “milk heifers.” It is assumed that the number of dairy cow replacements 0 to 12 months old was equivalent to the number 12 to 24 months old replacements.

Step 4: Estimate Methane Emissions from Beef Cattle

Beef cattle methane emissions were estimated by multiplying published cattle populations by emission factors. Emissions from beef cows and replacements were estimated using state population data and regional emission developed in EPA (1993), as shown in Table G-3. Emissions from slaughter cattle and bulls were estimated using national data and emission factors. The emission factors for slaughter animals represent their entire life, from birth to slaughter. Consequently, the emission factors were multiplied by the national data on total steer and heifer slaughters rather than live populations of calves, heifers, and steers grown for slaughter. Slaughter population numbers were taken from and USDA datasets. The Weanling and Yearling mix was unchanged from earlier estimates derived from discussions with industry representatives.

Step 5: Estimate Methane Emissions from Other Livestock

Methane emissions from sheep, goats, swine, and horses were estimated by multiplying published national population estimates by the national emission factor for each year.

A summary of emissions is provided in Table G-4. Emission factors, national average or regional, are shown by animal type in Table G-5.

Table G-1: Livestock Population (thousand head)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997
Dairy								
Cows	10,007	9,883	9,714	9,679	9,514	9,494	9,409	9,304
Replacements 0-12	4,135	4,097	4,116	4,088	4,072	4,021	3,902	3,828
Replacements 12-24	4,135	4,097	4,116	4,088	4,072	4,021	3,902	3,828
Beef								
Cows	32,677	32,960	33,453	34,132	35,325	35,628	35,414	34,486
Replacements 0-12	5,141	5,321	5,621	5,896	6,133	6,087	5,839	5,678
Replacements 12-24	5,141	5,321	5,621	5,896	6,133	6,087	5,839	5,678
Slaughter-Weanlings	5,199	5,160	5,150	5,198	5,408	5,612	5,580	5,692
Slaughter-Yearlings	20,794	20,639	20,600	20,794	21,632	22,450	22,322	22,767
Bulls	2,180	2,198	2,220	2,239	2,304	2,395	2,346	2,320
Other								
Sheep	11,356	11,174	10,797	10,201	9,742	8,886	8,454	7,607
Goats	2,545	2,475	2,645	2,605	2,595	2,495	2,495	2,295
Horses	5215	5650	5650	5850	5900	6000	6,000	6,150
Hogs	54,014	56,478	58,532	57,999	60,018	59,792	56,716	58,671

Table G-2: Dairy Cow CH_4 Emission Factors and Milk Production Per Cow

Region	1990	1991	1992	1993	1994	1995	1996	1997
Dairy Cow Emission Factors (kg/head)								
North Atlantic	116.2	118.8	121.3	121.0	122.3	124.7	124.8	125.8
South Atlantic	127.7	128.7	132.3	132.2	134.5	134.4	132.9	136.5
North Central	105.0	105.7	107.8	107.6	109.8	111.2	110.0	111.8
South Central	116.2	116.1	117.9	119.2	121.1	122.2	120.9	120.5
West	130.4	129.4	132.7	132.3	135.6	134.8	137.3	139.4
Milk Production (kg/year)								
North Atlantic	6,574	6,811	7,090	7,055	7,185	7,424	7,440	7,542
South Atlantic	6,214	6,300	6,622	6,608	6,813	6,792	6,673	6,990
North Central	6,334	6,413	6,640	6,627	6,862	6,987	6,881	7,080
South Central	5,696	5,687	5,849	5,971	6,148	6,248	6,128	6,098
West	8,339	8,255	8,573	8,530	8,874	8,789	9,047	9,260

Table G-3: CH_4 Emission Factors Beef Cows and Replacements (kg/head/yr)

Region	Replacements (0-12)	Replacements (12-24)	Mature Cows
North Atlantic	19.2	63.8	61.5
South Atlantic	22.7	67.5	70.0
North Central	20.4	60.8	59.5
South Central	23.6	67.7	70.9
West	22.7	64.8	69.1

Table G-4: Methane Emissions from Livestock Enteric Fermentation (Tg)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997
Dairy	**1.47**	**1.46**	**1.47**	**1.47**	**1.47**	**1.47**	**1.46**	**1.45**
Cows	1.15	1.14	1.15	1.15	1.15	1.16	1.15	1.15
Replacements 0-12	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
Replacements 12-24	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.23
Beef	**3.95**	**3.98**	**4.04**	**4.12**	**4.27**	**4.34**	**4.29**	**4.24**
Cows	2.18	2.20	2.23	2.28	2.36	2.38	2.36	2.30
Replacements 0-12	0.11	0.12	0.13	0.13	0.14	0.14	0.13	0.13
Replacements 12-24	0.33	0.35	0.37	0.38	0.40	0.40	0.38	0.37
Slaughter-Weanlings	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.13
Slaughter-Yearlings	0.98	0.98	0.97	0.98	1.02	1.06	1.06	1.08
Bulls	0.22	0.22	0.22	0.22	0.23	0.24	0.23	0.23
Other	**0.28**	**0.29**	**0.29**	**0.29**	**0.29**	**0.28**	**0.27**	**0.27**
Sheep	0.09	0.09	0.09	0.08	0.08	0.07	0.07	0.06
Goats	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Horses	0.09	0.10	0.10	0.11	0.11	0.11	0.11	0.11
Hogs	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09
Total	**5.70**	**5.73**	**5.80**	**5.88**	**6.03**	**6.10**	**6.02**	**5.96**

Table G-5: Enteric Fermentation CH_4 Emission Factors

Animal Type	kg/head/year
Dairy	
Cows	regional
Replacements 0-12	19.6
Replacements 12-24	58.8
Beef	
Cows	regional
Replacements 0-12	regional
Replacements 12-24	regional
Slaughter-Weanlings	23.1
Slaughter-Yearlings	47.3
Bulls	100.0
Other	
Sheep	8.0
Goats	5.0
Horses	18.0
Hogs	1.5

Annex H

Methodology for Estimating Methane Emissions from Manure Management

The following steps were used to estimate methane emissions from the management of livestock manure.

Step 1: Collect Livestock Population Data

All livestock population data, except for horses, were taken from U.S. Department of Agriculture (USDA) statistical reports. For each animal category, the USDA publishes monthly, annual, and multi-year livestock population and production estimates. Multi-year reports include revisions to earlier published data. Recent reports were obtained from the USDA Economics and Statistics System website, at <http://www.mannlib.cornell.edu/usda/>, while historical data were downloaded from the USDA National Agricultural Statistics Service (NASS) website at <http://www.usda.gov/nass/pubs/dataprd1.htm>.

Dairy cow and swine population data by farm size for each state, used in Step 2, were found in the *1992 Census of Agriculture* published by the U.S. Department of Commerce (DOC). This census is conducted every five years. Data from the census were obtained from the USDA NASS website at <http://www.nass.usda.gov/census/>.

The Food and Agriculture Organization (FAO) publishes horse population data. These data weree accessed from the FAOSTAT database at <http://apps.fao.org/>. Table H-1 summarizes the published population data by animal type.

Step 2: Estimate State Methane Conversion Factors for Dairy Cows and Swine

Data from EPA (1993) were used for assessing dairy and swine manure management practices by farm size. Based on this assessment, an average methane conversion factor (MCF) was assigned to each farm size category for dairy and swine farms, indicating the portion of the methane producing potential realized. Because larger farms tend to use liquid manure management systems, which produce more methane, the MCFs applied to them were higher for smaller farm sizes.

Using the dairy cow and swine populations by farm size in the DOC *Census of Agriculture* for each state, weighted average dairy and swine MCFs were calculated for each state. The MCF value for each state reflected the distribution of animals among farm sizes within the state. Table H-2 provides estimated MCF values.

Step 3: Estimate Methane Emissions from Swine

For each state, the total swine population was multiplied by volatile solids (VS) production rates to determine total VS production. Estimated state level emissions were calculated as the product of total VS production multiplied by the maximum methane production potential for swine manure (B_o), and the state MCF. Total U.S. emissions are the sum of the state level emissions. The VS production rate and maximum methane production potential are shown in Table H-3.

Step 4: Estimate Methane Emissions from Dairy Cattle

Methane emissions from dairy cow manure were estimated using the same method as emissions from swine (Step 3), but with an added analysis to estimate changes in manure production associated with changes in feed intake, or dry matter intake (DMi). It is assumed that manure and VS production will change linearly with changes in dry matter intake (DMi).

Changes in DMi were calculated reflecting changes in feed intake associated with changes in milk production per cow per year. To estimate the changes in feed intake, a simplified emission factor model was used for dairy cow enteric fermentation emissions (see Annex G). This model estimates the change in DMi over time relative to 1990, which was used to calculate VS production by dairy cows by state, as summarized in the following equation: (Dairy cow population) x (VS produced per cow) x (DMi scaling factor). Methane emissions were then calculated as follows:

(VS produced) x (Maximum methane production potential for dairy cow manure) x (State-specific MCF). Total emissions were finally calculated as the sum of the state level emissions. The 1990 VS production rate and maximum methane production potential are shown in Table H-3.

Step 5: Estimate Methane Emissions for Other Animals

The 1990 methane emissions for the other animal types were estimated using the detailed method described above for dairy cows and swine (EPA 1993). This process was not repeated for subsequent years for these other animal types. Instead, national populations of each of the animal types were used to scale the 1990 emissions estimates to the period 1991 through 1997.

Emission estimates are summarized in Table H-4.

Table H-1: Livestock Population (1000 head)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997
Dairy Cattle	**14,143**	**13,980**	**13,830**	**13,767**	**13,686**	**13,514**	**13,310**	**13,133**
Dairy Cows	10,007	9,883	9,714	9,679	9,614	9,493	9,408	9,304
Dairy Heifers	4,135	4,097	4,116	4,088	4,072	4,021	3,902	3,828
Swine	**54,014**	**56,478**	**58,532**	**57,999**	**60,018**	**59,792**	**56,716**	**58,671**
Beef Cattle	**86,065**	**87,266**	**88,546**	**90,317**	**92,754**	**94,364**	**93,683**	**91,997**
Feedlot Steers	7,252	7,927	7,404	7,838	8,063	7,635	7,822	7,925
Feedlot Heifers	3,753	4,144	3,884	4,094	4,088	3,934	4,063	4,126
Feedlot Cow/Other	88	98	92	95	93	97	96	97
NOF Bulls	2,180	2,198	2,220	2,239	2,304	2,395	2,346	2,320
NOF Calves	23,909	23,854	24,118	24,209	24,692	25,184	24,644	24,355
NOF Heifers	8,740	8,828	9,261	9,727	10,179	10,790	10,800	10,751
NOF Steers	7,554	7,356	8,208	8,081	8,108	8,796	8,594	8,035
NOF Cows	32,589	32,860	33,359	34,033	35,227	35,531	35,318	34,389
Sheep	**11,356**	**11,174**	**10,797**	**10,201**	**9,742**	**8,886**	**8,454**	**7.607**
Ewes>1yr	7,961	7,799	7,556	7,140	6,775	6,184	5,875	5,317
Rams/Weth>1yr	369	361	350	331	314	282	269	244
Ewes<1yr	1,491	1,464	1,432	1,349	1,277	1,167	1,107	1,011
Rams/Weth<1yr	381	373	366	348	332	296	282	258
Sheep on Feed	1,154	1,177	1,093	1,032	1,044	957	921	777
Goats	**2,545**	**2,475**	**2,645**	**2,605**	**2,595**	**2,495**	**2,495**	**2,295**
Poultry	**1,703,037**	**1,767,513**	**1,832,308**	**1,895,851**	**1,971,404**	**2,031,455**	**2,091,364**	**2,140,362**
Hens>1yr	119,551	117,178	121,103	131,688	134,876	133,767	137,944	140,686
Pullets laying	153,916	162,943	163,397	158,938	163,628	164,526	165,304	170,398
Pullets>3mo	34,222	34,272	34,710	33,833	32,808	32,813	31,316	34,174
Pullets<3mo	38,945	42,344	45,160	47,941	44,875	45,494	44,611	50,693
Chickens	6,546	6,857	7,113	7,240	7,319	7,641	7,243	7,544
Broilers	1,172,830	1,227,430	1,280,498	1,338,862	1,403,508	1,465,134	1,519,640	1,552,052
Other (Lost)	6,971	7,278	7,025	6,992	12,744	8,152	8,124	9,972
Other (Sold)	41,672	39,707	41,538	39,606	40,272	40,917	39,588	38,198
Turkeys	128,384	129,505	131,764	130,750	131,375	133,012	137,595	136,645
Horses	**5,650**	**5,650**	**5,850**	**5,900**	**6,000**	**6,000**	**6,050**	**6,150**

Table H-2: Dairy Cow and Swine CH_4 Conversion Factors

State	Dairy Cow	Swine
AK	0.35	0.35
AL	0.23	0.28
AR	0.45	0.59
AZ	0.09	0.68
CA	0.44	0.44
CO	0.31	0.46
CT	0.19	0.01
DE	0.21	0.29
FL	0.41	0.23
GA	0.27	0.35
HI	0.40	0.40
IA	0.04	0.38
ID	0.23	0.27
IL	0.07	0.42
IN	0.06	0.43
KS	0.09	0.33
KY	0.06	0.30
LA	0.19	0.30
MA	0.13	0.40
MD	0.15	0.42
ME	0.10	0.01
MI	0.12	0.42
MN	0.04	0.38
MO	0.07	0.33
MS	0.17	0.35

State	Dairy Cow	Swine
MT	0.16	0.39
NC	0.20	0.65
ND	0.05	0.22
NE	0.08	0.34
NH	0.12	0.36
NJ	0.13	0.26
NM	0.42	0.47
NV	0.36	0.50
NY	0.11	0.22
OH	0.07	0.30
OK	0.13	0.31
OR	0.25	0.35
PA	0.06	0.35
RI	0.07	0.59
SC	0.29	0.40
SD	0.06	0.26
TN	0.14	0.28
TX	0.31	0.30
UT	0.21	0.34
VA	0.17	0.34
VT	0.11	0.09
WA	0.29	0.29
WI	0.05	0.27
WV	0.11	0.11
WY	0.12	0.20

Table H-3: Dairy Cow and Swine Constants

Description	Dairy Cow	Swine	Source
Typical Animal Mass (kg)	640	150	ASAE 1995
kg VS/day per 1000 kg mass	10	8.5	ASAE 1995
Maximum methane generation potential (B_o) m^3 methane/kg VS	0.24	0.47	EPA 1992

Table H-4: CH_4 Emissions from Livestock Manure Management (Tg)

Animal Type	1990	1991	1992	1993	1994	1995	1996	1997
Dairy Cattle	**0.75**	**0.75**	**0.76**	**0.77**	**0.79**	**0.79**	**0.79**	**0.81**
Dairy Cows	0.58	0.59	0.60	0.61	0.63	0.63	0.64	0.65
Dairy Heifers	0.17	0.16	0.17	0.16	0.16	0.16	0.16	0.15
Swine	**1.37**	**1.44**	**1.51**	**1.51**	**1.58**	**1.60**	**1.55**	**1.62**
Beef Cattle	**0.20**	**0.20**	**0.21**	**0.21**	**0.22**	**0.22**	**0.23**	**0.23**
Feedlot Steers	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Feedlot Heifers	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Feedlot Cow/Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NOF Bulls	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
NOF Calves	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
NOF Heifers	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
NOF Steers	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02
NOF Cows	0.10	0.10	0.10	0.10	0.11	0.11	0.11	0.11
Sheep	**0.004**	**0.004**	**0.004**	**0.003**	**0.003**	**0.003**	**0.003**	**0.003**
Ewes > 1 yr	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.002
Rams/Weth > 1 yr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Ewes < 1 yr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Rams/Weth < 1 yr	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Sheep on Feed	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Goats	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**	**0.001**
Poultry	**0.26**	**0.27**	**0.28**	**0.28**	**0.29**	**0.30**	**0.30**	**0.31**
Hens > 1 yr	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06
Pullets laying	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Pullets > 3 mo	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Pullets < 3 mo	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Chickens	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Broilers	0.10	0.10	0.11	0.11	0.12	0.12	0.13	0.13
Other (Lost)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other (Sold)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Turkeys	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Horses	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**	**0.03**

Annex I
Methodology for Estimating Methane Emissions from Landfills

Landfill methane is produced from a complex process of waste decomposition and subsequent fermentation under anaerobic conditions. The total amount of methane produced in a landfill from a given amount of waste and the rate at which it is produced depends upon the characteristics of the waste, the climate, and operating practices at the landfill. To estimate the amount of methane produced in a landfill in a given year the following information is needed: quantity of waste in the landfill, the waste characteristics, the residence time of the waste in the landfill, and landfill management practices.

The amount of methane emitted from a landfill is less than the amount of methane produced in a landfill. If no measures are taken to extract the methane, a portion of the methane will oxidize as it travels through the top layer of the landfill cover. The portion of the methane that oxidizes turns primarily to carbon dioxide (CO_2). If the methane is extracted and combusted (e.g., flared or used for energy), then that portion of the methane produced in the landfill will not be emitted as methane, but again would be converted to CO_2. In general, the CO_2 emitted is of biogenic origin and primarily results from the decomposition—either aerobic or anaerobic—of organic matter such as food or yard wastes.[8]

To take into account the inter-related processes of methane production in the landfill and methane emission, this analysis relied on a simulation of the population of landfills and waste disposal. A starting population of landfills was initialized with characteristics from the latest survey of municipal solid waste (MSW) landfills (EPA 1988). Using actual national waste disposal data, waste was simulated to be placed in these landfills each year from 1990 to 1997. If landfills reached their design capacity, they were simulated to have closed. New landfills were simulated to open only if annual disposal capacity was less than total waste disposal. Of note is that closed landfills continue to produce and emit methane for many years. This analysis tracks these closed landfills throughout the analysis period, and includes their estimated methane production and emissions.

The age of the waste in each landfill was tracked explicitly. This tracking allowed the annual methane production in each landfill to be estimated. Methane produced in industrial landfills was also estimated. It was assumed to be 7 percent of the total methane produced in MSW landfills. Finally, methane recovered and combusted and methane oxidized were subtracted to estimate final methane emissions.

Using this approach, landfill population and waste disposal characteristics were simulated over time explicitly, thereby allowing the time-dependent nature of methane production to be modeled. However, the characteristics used to initialize the landfill population in the model were relatively old and may not represent the current set of operating landfills adequately. There is also uncertainty in the methane production equation developed in EPA (1993), as well as in the estimate of methane oxidation (10 percent).

Step 1: Estimate Municipal Solid Waste in Place Contributing to Methane Emissions

The landfill population model was initialized to define the population of landfills at the beginning of 1990. Waste was simulated to be placed into these landfills for the years 1990 through 1997 using data on the total waste landfilled from BioCycle (1998). The annual acceptance rates of the landfills were used to apportion the total waste by landfill. More waste was preferentially disposed in "Large" landfills (see Table I-3), reflecting the trend toward fewer and more centralized disposal facilities. The model updates the landfill characteristics each year, calculating the total waste in place and the full time profile of waste disposal. This time profile was used to estimate the portion of the waste that contributes to methane emissions. Table I-1 shows the amount of waste landfilled each year and the total estimated waste in place contributing to methane emissions.

[8] Emissions and sinks of biogenic carbon are accounted for in the Land-Use Change and Forestry chapter.

Step 2: Estimate Landfill Methane Production

Emissions for each landfill were estimated by applying the emissions model (EPA 1993) to the landfill waste in place contributing to methane production. Total emissions were then calculated as the sum of emissions from all landfills.

Step 3: Estimate Industrial Landfill Methane Production

Industrial landfills receive waste from factories, processing plants, and other manufacturing activities. Because there were no data available on methane generation at industrial landfills, the approach used was to assume that industrial methane production equaled about 7 percent of MSW landfill methane production (EPA 1993), as shown below in Table I-2.

Step 4: Estimate Methane Recovery

To estimate landfill gas (LFG) recovered per year, data on current and planned LFG recovery projects in the United States were obtained from Governmental Advisory Associates (GAA 1994). The GAA report, considered to be the most comprehensive source of information on gas recovery in the United States, has estimates for gas recovery in 1990 and 1992. Their data set showed that 1.20 and 1.44 teragrams (Tg) of methane were recovered nationally by municipal solid waste landfills in 1990 and 1992, respectively. In addition, a number of landfills were believed to recover and flare methane without energy recovery and were not included in the GAA database. To account for the amount of methane flared without energy recovery, the estimate of gas recovered was increased by 25 percent (EPA 1993). Therefore, net methane recovery from landfills was assumed to equal 1.50 Tg in 1990, and 1.80 Tg in 1992. The 1990 estimate of methane recovered was used for 1991 and the 1992 estimate was used for the period 1992 to 1997. EPA is currently reviewing more detailed information on LFG recovery projects and expects that the total recovery figure could be significantly higher.

Step 5: Estimate Methane Oxidation

As discussed above, a portion of the methane escaping from a landfill through its cover oxidizes in the top layer of the soil. The amount of oxidation that occurs is uncertain and depends upon the characteristics of the soil and the environment. For purposes of this analysis, it was assumed that 10 percent of the methane produced was oxidized in the soil.

Step 6: Estimate Total Methane Emissions

Total methane emissions were calculated by adding emissions from MSW and industrial waste, and subtracting methane recovered and oxidized, as shown in Table I-2.

Table I-1: Municipal Solid Waste (MSW) Contributing to CH_4 Emissions (Tg)

Variable	1990	1991	1992	1993	1994	1995	1996	1997
Total MSW Generated[a]	267	255	265	279	293	297	297	309
Percent of MSW Landfilled[a]	77%	76%	72%	71%	67%	63%	62%	61%
Total MSW Landfilled	206	194	191	198	196	187	184	189
MSW Contributing to Emissions[b]	4,926	5,027	5,162	5,292	5,428	5,560	5,677	5,791

[a] Source: BioCycle (1998). The data, originally reported in short tons, are converted to metric tons.
[b] The EPA emissions model (EPA 1993) defines all waste younger than 30 years as contributing to methane emissions.

Table I-2: CH_4 Emissions from Landfills (Tg)

Activity	1990	1991	1992	1993	1994	1995	1996	1997
MSW Generation	11.6	11.8	12.2	12.5	12.8	13.2	13.5	13.8
Large Landfills	4.53	4.62	4.76	4.91	5.11	5.29	5.45	5.64
Medium Landfills	5.79	5.91	6.07	6.23	6.36	6.53	6.62	6.70
Small Landfills	1.27	1.30	1.33	1.36	1.39	1.41	1.42	1.44
Industrial Generation	0.73	0.75	0.77	0.79	0.81	0.83	0.85	0.87
Potential Emissions	12.3	12.6	12.9	13.3	13.7	14.1	14.3	14.7
Recovery	(1.50)	(1.50)	(1.80)	(1.80)	(1.80)	(1.80)	(1.80)	(1.80)
Oxidation	(1.09)	(1.12)	(1.12)	(1.16)	(1.19)	(1.23)	(1.26)	(1.20)
Net Emissions	**9.82**	**10.0**	**10.1**	**10.4**	**10.8**	**11.1**	**11.4**	**11.6**

Note: Totals may not sum due to independent rounding.

Table I-3: Municipal Solid Waste Landfill Size Definitions (Tg)

Description	Waste in Place
Small Landfills	< 0.4
Medium Landfills	0.4 - 2.0
Large Landfills	> 2.0

Annex J

Global Warming Potential Values

Table J-1: Global Warming Potentials and Atmospheric Lifetimes (years)

Gas	Atmospheric Lifetime	GWP[a]
Carbon dioxide (CO_2)	50-200	1
Methane (CH_4)[b]	12±3	21
Nitrous oxide (N_2O)	120	310
HFC-23	264	11,700
HFC-125	32.6	2,800
HFC-134a	14.6	1,300
HFC-143a	48.3	3,800
HFC-152a	1.5	140
HFC-227ea	36.5	2,900
HFC-236fa	209	6,300
HFC-4310mee	17.1	1,300
CF_4	50,000	6,500
C_2F_6	10,000	9,200
C_4F_{10}	2,600	7,000
C_6F_{14}	3,200	7,400
SF_6	3,200	23,900

Source: (IPCC 1996)

[a] 100 year time horizon

[b] The methane GWP includes the direct effects and those indirect effects due to the production of tropospheric ozone and stratospheric water vapor. The indirect effect due to the production of CO_2 is not included.

Annex K
Ozone Depleting Substance Emissions

Ozone is present in both the stratosphere[9], where it shields the Earth from harmful levels of ultraviolet radiation, and at lower concentrations in the troposphere[10], where it is the main component of anthropogenic photochemical "smog". Chlorofluorocarbons (CFCs) and other compounds that contain chlorine or bromine have been found to destroy ozone in the stratosphere, and are commonly referred to as ozone-depleting substances (ODSs). If left unchecked, ozone depletion could result in a dangerous increase of ultraviolet radiation reaching the earth's surface. In 1987, nations around the world signed the *Montreal Protocol on Substances that Deplete the Ozone Layer*. This landmark agreement created an international framework for limiting, and ultimately eliminating, the use and emission of most ozone depleting substances, which are used in a variety of industrial applications, including refrigeration and air conditioning, foam blowing, fire extinguishing, aerosol propellants, sterilization, and solvent cleaning.

In the United States, the Clean Air Act Amendments of 1990 provide the legal instrument for implementation of the *Montreal Protocol* controls. The Clean Air Act classifies ozone depleting substances as either Class I or Class II, depending upon the ozone depletion potential (ODP) of the compound.[11] The production of CFCs, halons, carbon tetrachloride, and methyl chloroform, all Class I substances, has already ended in the United States. However, because stocks of these chemicals remain available and in use, they will continue to be emitted for many years from applications such as refrigeration and air conditioning equipment, fire extinguishing systems, and metered dose inhalers. As a result, emissions of Class I compounds will continue, in ever decreasing amounts, into the early part of the next century. Class II substances, which are comprised of hydrochlorofluorocarbons (HCFCs), are being phased-out at a later date because of their lower ozone depletion potentials. These compounds are serving as interim replacements for Class I compounds in many industrial applications. The use and emissions of HCFCs in the United States is anticipated to increase over the next several years. Under current controls, the production of all HCFCs in the United States will end by the year 2030.

In addition to contributing to ozone depletion, CFCs, halons, carbon tetrachloride, methyl chloroform, and HCFCs are also significant greenhouse gases. The total impact of ozone depleting substances on global warming is not clear, however, because ozone is also a greenhouse gas. The depletion of ozone in the stratosphere by ODSs has an indirect negative radiative forcing, while most ODSs have a positive direct radiative forcing effect. The IPCC has prepared both direct GWPs and net (i.e., combined direct and indirect effects) GWP ranges for some of the most common ozone depleting substances (IPCC 1996). Direct GWPs account for the direct global warming impact of the emitted gas. Net GWP ranges account for both the direct impact of the emitted gas and the indirect effects resulting from the destruction of ozone.

Although the IPCC emission inventory guidelines do not include reporting emissions of ozone depleting substances, the United States believes that no inventory is complete without the inclusion of these emissions. Emission estimates for several ozone depleting substances are provided in Table K-1.

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[9] The stratosphere is the layer from the top of the troposphere up to about 50 kilometers. Approximately 90 percent of atmospheric ozone lies within the stratosphere. The greatest concentration of ozone occurs in the middle of the stratosphere, in a region commonly called the ozone-layer.

[10] The troposphere is the layer from the ground up to about 11 kilometers near the poles and 16 kilometers in equatorial regions (i.e., the lowest layer of the atmosphere, where humans live). It contains roughly 80 percent of the mass of all gases in the atmosphere and is the site for weather processes including most of the water vapor and clouds.

[11] Substances with an ozone depletion potential of 0.2 or greater are classified as Class I. All other substances that may deplete stratospheric ozone but which do not have an ODP of 0.2 or greater, are classified as Class II.

Table K-1: Emissions of Ozone Depleting Substances (Mg)

Compound	1990	1991	1992	1993	1994	1995	1996	1997
Class I								
CFC-11	53,500	48,300	45,100	45,400	36,600	36,200	26,600	25,100
CFC-12	112,600	103,500	80,500	79,300	57,600	51,800	35,500	23,100
CFC-113	26,350	20,550	17,100	17,100	8,550	8,550	+	+
CFC-114	4,700	3,600	3,000	3,000	1,600	1,600	300	100
CFC-115	4,200	4,000	3,800	3,600	3,300	3,000	3,200	2,900
Carbon Tetrachloride	32,300	31,000	21,700	18,600	15,500	4,700	+	+
Methyl Chloroform	158,300	154,700	108,300	92,850	77,350	46,400	+	+
Halon-1211	1,000	1,100	1,000	1,100	1,000	1,100	1,100	1,100
Halon-1301	1,800	1,800	1,700	1,700	1,400	1,400	1,400	1,300
Class II								
HCFC-22	79,789	79,540	79,545	71,224	71,386	74,229	77,472	79,620
HCFC-123	+	+	285	570	844	1,094	1,335	1,555
HCFC-124	+	+	429	2,575	4,768	5,195	5,558	5,894
HCFC-141b	+	+	+	1,909	6,529	11,608	14,270	12,113
HCFC-142b	+	+	3,526	9,055	14,879	21,058	27,543	28,315
HCFC-225ca/cb	+	+	+	+	+	565	579	593

Source: EPA estimates
+ Does not exceed 10 Mg

Methodology and Data Sources

Emissions of ozone depleting substances were estimated using two simulation models: the Atmospheric and Health Effects Framework (AHEF) and EPA's Vintaging Model.

The Atmospheric and Health Effects Framework model contains estimates of U.S. domestic use of each of the ozone depleting substances. These estimates were based upon data that industry reports to EPA and other published material. The annual consumption of each compound was divided into various end-uses based upon historical trends and research into specific industrial applications. These end-uses include refrigerants, foam blowing agents, solvents, aerosol propellants, sterilants, and fire extinguishing agents.

With the exception of aerosols, solvents, and certain foam blowing agents, emissions of ozone depleting substances are not instantaneous, but instead occur gradually over time (i.e., emissions in a given year are the result of both ODS use in that year and use in previous years). Each end-use has a certain release profile, which gives the percentage of the compound that is released to the atmosphere each year until all releases have occurred. In refrigeration equipment, for example, the initial charge is released or leaked slowly over the lifetime of the equipment, which could be 20 or more years. In addition, not all of the refrigerant is ultimately emitted—some will be recovered when the equipment is retired from operation.

The AHEF model was used to estimate emissions of ODSs that were in use prior to the controls implemented under the *Montreal Protocol*. This included CFCs, halons, carbon tetrachloride, methyl chloroform, and HCFC-22. Certain HCFCs, such as HCFC-123, HCFC-124, HCFC-141b, HCFC-142b, HCFC-225ca and HCFC-225cb, have also entered the market as interim substitutes for ODSs. Emissions estimates for these compounds were taken from EPA's Vintaging Model.

The Vintaging Model was used to estimate the use and emissions of various ODS substitutes, including HCFCs. The name refers to the fact that the model tracks the use and emissions of various compounds by the annual "vintages" of new equipment that enter service in each end-use. The Vintaging Model is a "bottom-up" model. Information was collected regarding the sales of equipment that use ODS substitutes and the amount of the chemical required by each unit of equipment. Emissions for each end-use were estimated by applying annual leak rates and release profiles, as in the AHEF. By aggregating the data for more than 40 different end-uses, the model produces estimates of annual use and emissions of each compound.

Uncertainties

Uncertainties exist with regard to the levels of chemical production, equipment sales, equipment characteristics, and end-use emissions profiles that are used by these models.

Annex L
Sulfur Dioxide Emissions

Sulfur dioxide (SO_2) emitted into the atmosphere through natural and anthropogenic processes affects the Earth's radiative budget through photochemical transformation into sulfate aerosols that can (1) scatter sunlight back to space, thereby reducing the radiation reaching the Earth's surface; (2) affect cloud formation; and (3) affect atmospheric chemical composition (e.g., stratospheric ozone, by providing surfaces for heterogeneous chemical reactions). The overall effect of SO_2 derived aerosols on radiative forcing is believed to be negative (IPCC 1996). However, because SO_2 is short-lived and unevenly distributed through the atmosphere, its radiative forcing impacts are highly uncertain. Sulfur dioxide emissions have been provided below in Table L-1.

The major source of SO_2 emissions in the United States was the burning of sulfur containing fuels, mainly coal. Metal smelting and other industrial processes also released significant quantities of SO_2. As a result, the largest contributors to overall U.S. emissions of SO_2 were electric utilities, accounting for 64 percent in 1997 (see Table L-2). Coal combustion accounted for approximately 96 percent of SO_2 emissions from electric utilities in the same year. The second largest source was industrial fuel combustion, which produced 17 percent of 1997 SO_2 emissions. Overall, sulfur dioxide emissions in the United States decreased by 16 percent from 1990 to 1997. Seventy-six percent of this decline came from reductions from electric utilities, primarily due to increased consumption of low sulfur coal from surface mines in western states.

Sulfur dioxide is important for reasons other than its effect on radiative forcing. It is a major contributor to the formation of urban smog and acid rain. As a contributor to urban smog, high concentrations of SO_2 can cause significant increases in acute and chronic respiratory diseases. In addition, once SO_2 is emitted, it is chemically transformed in the atmosphere and returns to earth as the primary contributor to acid deposition, or acid rain. Acid rain has been found to accelerate the decay of building materials and paints, and to cause the acidification of lakes and streams and damage trees. As a result of these harmful effects, the United States has regulated the emissions of SO_2 under the Clean Air Act. The EPA has also developed a strategy to control these emissions via four programs: (1) the National Ambient Air Quality Standards program,[12] (2) New Source Performance Standards,[13] (3) the New Source Review/Prevention of Significant Deterioration Program,[14] and (4) the sulfur dioxide allowance program.[15]

References

EPA (1998) *National Air Pollutant Emissions Trends Report, 1900-1997*, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC.

[12] [42 U.S.C § 7409, CAA § 109]
[13] [42 U.S.C § 7411, CAA § 111]
[14] [42 U.S.C § 7473, CAA § 163]
[15] [42 U.S.C § 7651, CAA § 401]

Table L-1: SO_2 Emissions (Gg)

Sector/Source	1990	1991	1992	1993	1994	1995	1996	1997
Energy	**20,526**	**20,031**	**19,851**	**19,514**	**19,003**	**16,583**	**16,804**	**17,258**
Stationary Sources	18,407	17,959	17,684	17,459	17,134	14,724	15,253	15,658
Mobile Sources	1,728	1,729	1,791	1,708	1,524	1,525	1,217	1,252
Oil and Gas Activities	390	343	377	347	344	334	334	349
Industrial Processes	**1,306**	**1,187**	**1,186**	**1,159**	**1,135**	**1,116**	**1,125**	**1,175**
Chemical Manufacturing	269	254	252	244	249	260	260	273
Metals Processing	658	555	558	547	510	481	481	501
Storage and Transport	6	9	8	4	1	2	2	2
Other Industrial Processes	362	360	360	355	361	365	371	387
Miscellaneous*	11	10	9	8	13	8	12	12
Solvent Use	**+**	**+**	**+**	**1**	**1**	**1**	**1**	**1**
Degreasing	+	+	+	+	+	+	+	+
Graphic Arts	+	+	+	+	+	+	+	+
Dry Cleaning	NA	NA	+	NA	+	+	+	+
Surface Coating	+	+	+	+	+	+	+	+
Other Industrial	+	+	+	+	+	+	+	+
Non-industrial	NA	NA	NA	NA	NA	NA	NA	NA
Agriculture	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
Agricultural Burning	NA	NA	NA	NA	NA	NA	NA	NA
Waste	**38**	**40**	**40**	**65**	**54**	**43**	**43**	**45**
Waste Combustion	38	39	39	56	48	42	42	44
Landfills	+	+	+	+	+	+	+	+
Wastewater Treatment	+	+	+	+	+	1	1	1
Miscellaneous Waste	+	1	1	8	5	+	+	+
Total	**21,871**	**21,259**	**21,077**	**20,738**	**20,192**	**17,742**	**17,973**	**18,478**

Source: (EPA 1998)
* Miscellaneous includes other combustion and fugitive dust categories.
+ Does not exceed 0.5 Gg
NA (Not Available)
Note: Totals may not sum due to independent rounding.

Table L-2: SO_2 Emissions from Electric Utilities (Gg)

Fuel Type	1990	1991	1992	1993	1994	1995	1996	1997
Coal	13,807	13,687	13,448	13,179	12,985	10,526	11,010	11,368
Petroleum	580	591	495	555	474	375	395	440
Natural Gas	1	1	1	1	1	8	2	4
Misc. Internal Combustion	45	41	42	45	48	50	52	55
Total	**14,432**	**14,320**	**13,986**	**13,779**	**13,507**	**10,959**	**11,460**	**11,868**

Source: (EPA 1998)
Note: Totals may not sum due to independent rounding.

Annex M

Complete List of Sources

Chapter/Source	Gas(es)
Energy	
Carbon Dioxide Emissions from Fossil Fuel Combustion	CO_2
Stationary Sources (excluding CO_2)	CH_4, N_2O, CO, NO_x, NMVOC
Mobile Sources (excluding CO_2)	CH_4, N_2O, CO, NO_x, NMVOC
Coal Mining	CH_4
Natural Gas Systems	CH_4
Petroleum Systems	CH_4
Natural Gas Flaring and Criteria Pollutant Emissions from Oil and Gas Activities	CO_2, CO, NO_x, NMVOC
International Bunker Fuels	CO_2, CH_4, N_2O, CO, NO_x, NMVOC
Wood Biomass and Ethanol Consumption	CO_2
Non-Energy Use Carbon Stored	CO_2 (sink)
Industrial Processes	
Cement Manufacture	CO_2
Lime Manufacture	CO_2
Limestone and Dolomite Use	CO_2
Soda Ash Manufacture and Consumption	CO_2
Carbon Dioxide Consumption	CO_2
Iron and Steel Production	CO_2
Ammonia Manufacture	CO_2
Ferroalloy Production	CO_2
Petrochemical Production	CH_4
Silicon Carbide Production	CH_4
Adipic Acid Production	N_2O
Nitric Acid Production	N_2O
Substitution of Ozone Depleting Substances	HFCs, PFCs[a]
Aluminum Production	CO_2, CF_4, C_2F_6
HCFC-22 Production	HFC-23
Semiconductor Manufacture	HFCs, PFCs, SF_6[b]
Electrical Transmission and Distribution	SF_6
Magnesium Production and Processing	SF_6
Industrial Sources of Criteria Pollutants	CO, NO_x, NMVOC
Solvent Use	CO, NO_x, NMVOC
Agriculture	
Enteric Fermentation	CH_4
Manure Management	CH_4, N_2O
Rice Cultivation	CH_4
Agricultural Soil Management	N_2O
Agricultural Residue Burning	CH_4, N_2O, CO, NO_x
Land-Use Change and Forestry	
Changes in Forest Carbon Stocks	CO_2 (sink)
Changes in Non-Forest Soil Carbon Stocks	CO_2 (sink)
Waste	
Landfills	CH_4
Wastewater Treatment	CH_4
Human Sewage	N_2O
Waste Combustion	N_2O
Waste Sources of Criteria Pollutants	CO, NO_x, NMVOC

[a] In 1997, included HFC-23, HFC-125, HFC-134a, HFC-143a, HFC-152a, HFC-227ea, HFC-236fa, HFC-4310mee, C_4F_{10}, C_6F_{14}, PFC/PFPEs

[b] Included such gases as HFC-23, CF_4, C_2F_6, SF_6

Annex N
IPCC Reporting Tables

This annex contains a series of tables which summarize the emissions data discussed in the body of this report for the year 1997. The data in these tables conform with guidelines established by the IPCC (IPCC/UNEP/OECD/IEA 1997; vol. 1) for consistent international reporting of greenhouse gas emissions inventories. The format of these tables does not always correspond directly with the calculations discussed in the body of the report. In these instances, the data have been reorganized to conform to IPCC reporting guidelines.[16] As a result, slight differences may exist between the figures presented in the IPCC tables and those in the body of the report. These differences are merely an artifact of variations in reporting structures; total U.S. emissions are unaffected.

Title of Inventory	*Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1997*
Contact Name	Wiley Barbour
Title	Senior Analyst
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Address	Climate Policy and Programs Division (2175) 401 M Street, SW Washington, DC 20460
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E-Mail	barbour.wiley@epa.gov
Is uncertainty addressed?	Yes
Related documents filed with IPCC	Yes

16 An additional table has been added (Table 2, sheet 3) that addresses emissions of HFCs and PFCs by individual gas. The standard IPCC reporting format for these gases is not sufficiently detailed. It was not possible to disaggreggate by gas the emissions of halocarbons and SF_6 from certain source categories or portions of source categories. In these cases, aggregate Global Warming Potential weighted emissions are reported in million metric tons of carbon equivalents (MMTCE).

TABLE 1 SECTORAL REPORT FOR ENERGY (1997)
(Sheet 1 of 3)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)							
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CO_2**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
Total Energy	**5,390,398**	**10,025**	**256**	**20,352**	**65,493**	**8,217**	**17,258**
A Fuel Combustion Activities (Reference Approach)	**5,415,400**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
A Fuel Combustion Activities (Sectoral Approach)	**5,375,164**	**633**	**256**	**20,248**	**65,163**	**7,730**	**16,909**
1 Energy Industries	**1,951,908**	**24**	**27**	**5,605**	**368**	**46**	**11,868**
a Public Electricity and Heat Production	1,951,908	24	27	5,605	368	46	11,868
b Petroleum Refining [a]	IE	IE	IE	IE	IE	IE	IE
c Manufacture of Solid Fuels and Other Energy Industries [a]	IE	IE	IE	IE	IE	IE	IE
2 Manufacturing Industries and Construction	**1,125,447**	**151**	**18**	**2,967**	**1,007**	**197**	**3,053**
a Iron and Steel	-	-	-	-	-	-	-
b Non-Ferrous Metals	-	-	-	-	-	-	-
c Chemicals	-	-	-	-	-	-	-
d Pulp, Paper and Print	-	-	-	-	-	-	-
e Food Processing, Beverages and Tobacco	-	-	-	-	-	-	-
f Other (please specify)	NA	NA	NA	NA	NA	NA	NA

[a] Included under "Manufacturing Industries and Construction"
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 1 SECTORAL REPORT FOR ENERGY (1997)
(Sheet 2 of 3)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)							
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CO_2**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
3 Transport	**1,634,556**	**242.4**	**207.40**	**10,519**	**60,794**	**6,949**	**1,252**
a Civil Aviation	137,569	IE	IE	IE	IE	IE	IE
b Road Transportation	1,271,038	222.0	197.93	6,382	45,593	4,744	290
c Railways	32,371	IE	IE	IE	IE	IE	IE
d Navigation	56,402	IE	IE	IE	IE	IE	IE
e Miscellaneous Non-Highway	137,175	20.4	9.47	4,137	15,201	2,205	962
Pipeline Transport	IE	IE	IE	IE	IE	IE	IE
4 Other Sectors	**616,927**	**215.2**	**4.13**	**1,157**	**2,994**	**538**	**737**
a Commercial/Institutional	238,591	24.2	0.88	379	235	22	-
b Residential	378,335	191.0	3.25	779	2,759	515	-
c Agriculture/Forestry/Fishing	IE	IE	IE	IE	IE	IE	-
5 Other (U.S. Territories)	**46,326**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
B Fugitive Emissions from Fuels	**15,235**	**9,391.7**	**NE**	**104**	**330**	**488**	**349**
1 Solid Fuels	**NE**	**3,274.1**	**NE**	**NE**	**NE**	**NE**	**NE**
a Coal Mining	NE	3,274.1	NE	NE	NE	NE	NE
b Solid Fuel Transformation	NE	IE	NE	NE	NE	NE	NE
c Other (please specify)	NE	NE	NE	NE	NE	NE	NE
2 Oil and Natural Gas	**15,235**	**6,117.6**	**NE**	**104**	**330**	**488**	**349**
a Oil	NE	270.7	NE	-	-	-	-
b Natural Gas	NE	5,846.9	NE	-	-	-	-
c Venting and Flaring	15,235	IE	NE	-	-	-	-

Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 1 SECTORAL REPORT FOR ENERGY (1997)
(Sheet 3 of 3)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)							
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CO_2**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
Memo Items [a]							
International Bunkers	**97,542**	**1.8**	**2.76**	**1,448**	**111**	**46**	**NE**
Aviation	50,974	1.4	1.62	202	84	13	NE
Marine	46,568	0.4	1.15	1,246	27	33	NE
CO_2 Emissions from Biomass [b]	**216,561**						

[a] Not included in energy totals.
[b] CO_2 emission from biomass are estimated from energy production industries, industrial, transportation, residential, and commercial sectors. Estimates of non-CO_2 emissions are incorporated in sectoral estimates under heading A.1.
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 2 SECTORAL REPORT FOR INDUSTRIAL PROCESSES (1997)
(Sheet 1 of 3)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)													
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	HFCs		PFCs		SF_6 [c]	
								P	A	P	A	P	A
Total Industrial Processes	**65,155**	**75.4**	**91.77**	**781**	**7,689**	**2,622**	**1,175**	**[a]**	**[a]**	**[a]**	**[a]**	**2.723**	**1.534**
A Mineral Products	**63,926**	**NE**	**NE**	**IE**	**IE**	**IE**	**IE**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
1 Cement Production	37,459	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
2 Lime Production	14,223	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
3 Limestone and Dolomite Use	7,810	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
4 Soda Ash Production and Use	4,434	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
5 Asphalt Roofing	NE	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
6 Road Paving with Asphalt	NE	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
7 Other	NE	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
Glass Production	NE	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
Concrete Pumice Stone	NE	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
B Chemical Industry	**IE**	**75.4**	**91.77**	**151**	**1,168**	**415**	**273**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**
1 Ammonia Production [b]	26,122	NE	NE	-	-	-	-	NE	NE	NE	NE	NE	NE
2 Nitric Acid Production	NO	NE	45.27	-	-	-	-	NE	NE	NE	NE	NE	NE
3 Adipic Acid Production	NO	NE	46.49	-	-	-	-	NE	NE	NE	NE	NE	NE
4 Carbide Production	NE	0.8	NE	-	-	-	-	NE	NE	NE	NE	NE	NE
5 Petrochemicals	NE	74.6	NE	-	-	-	-	NE	NE	NE	NE	NE	NE
C Metal Production	**IE**	**NE**	**NE**	**93**	**2,237**	**66**	**501**	**NE**	**NE**	**[a]**	**[a]**	**0.460**	**0.460**
1 Iron and Steel Production [b]	86,080	NE	NE	-	-	-	-	NE	NE	NE	NE	NE	NE
2 Ferroalloys Production [b]	1,789	NE	NE	-	-	-	-	NE	NE	NE	NE	NE	NE
3 Aluminum Production [b]	5,296	NE	NE	-	-	-	-	NE	NE	[a]	[a]	NE	NE
4 SF_6 Used in Aluminum and Magnesium Foundries	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.460	0.460
5 Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

[a] Emissions of HFCs and PFCs are documented by gas in Table 2 Sheet 3.
[b] CO_2 emissions from ammonia, iron & steel production, ferroallyos production, and aluminum production are included in this table for informational purposes only. These estimates are not included in the national total, however, in order to prevent double counting. Emissions from these sources are included under non-energy use of fossil fuels in the IPCC Energy Sector.
[c] Totals for actual SF_6 exclude emissions from Semiconductor Manufacture, which are provided in Table 2 Sheet 3.
"A" Actual emissions based on Tier 2 Approach.
"P" Potential emissions based on Tier 1 Approach.
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 2 SECTORAL REPORT FOR INDUSTRIAL PROCESSES (1997)
(Sheet 2 of 3)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)													
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CO_2**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**	**HFCs**		**PFCs**		**SF_6**	
								P	**A**	**P**	**A**	**P**	**A**
D Other Production	**1,229**	**NE**	**NE**	**IE**	**IE**	**IE**	**IE**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
1 Pulp and Paper	NE	NE	NE	IE	IE	IE	IE	NA	NA	NA	NA	NA	NA
2 Food and Drink	NE	NE	NE	IE	IE	IE	IE	NA	NA	NA	NA	NA	NA
3 Carbon Dioxide	1,229	NE	NE	IE	IE	IE	IE	NA	NA	NA	NA	NA	NA
E Production of Halocarbons & SF_6	**NE**	**NE**	**NE**	**IE**	**IE**	**IE**	**IE**	**[a]**	**[a]**	**[a]**	**[a]**	**NE**	**NE**
1 By-product Emissions	NE	NE	NE	IE	IE	IE	IE	NA	[a]	NE	NE	NE	NE
2 Fugitive Emissions	NE	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
3 Other	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
F Consumption of Halocarbons & SF_6	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**[a]**	**[a]**	**[a]**	**[a]**	**2.263**	**1.074**
1 Refrigeration and Air Conditioning Equipment	NA	NA	NA	NA	NA	NA	NA	-	-	-	-	NE	NE
2 Foam Blowing	NA	NA	NA	NA	NA	NA	NA	-	-	-	-	NE	NE
3 Fire Extinguishers	NA	NA	NA	NA	NA	NA	NA	-	-	-	-	NE	NE
4 Aerosols	NA	NA	NA	NA	NA	NA	NA	-	-	-	-	NE	NE
5 Solvents	NA	NA	NA	NA	NA	NA	NA	-	-	-	-	NE	NE
6 Electrical Transmission and Distribution	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	2.263	1.074
G Other	**NA**	**NA**	**NA**	**538**	**4,285**	**2,141**	**401**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**
1 Storage and Transport	NA	NA	NA	6	24	1,249	2	NA	NA	NA	NA	NA	NA
2 Other Industrial Processes	NA	NA	NA	382	601	416	387	NA	NA	NA	NA	NA	NA
3 Miscellaneous	NA	NA	NA	150	3,660	476	12	NA	NA	NA	NA	NA	NA

[a] Emissions of HFCs and PFCs are documented by gas in Table 2 Sheet 3.
"A" Actual emissions based on Tier 2 Approach.
"P" Potential emissions based on Tier 1 Approach.
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 2 SECTORAL REPORT FOR INDUSTRIAL PROCESSES (1997)
(Sheet 3 of 3)

	Sectoral Report for National Greenhouse Gas Inventories											
	(MMTCE)		(Gg)									
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**Aggre-gate**	**Aggre-gate**	**HFC-23**	**HFC-125**	**HFC-134a**	**HFC-143a**	**HFC-236fa**	**HFC-4310mee**	**CF_4**	**C_2F_6**	**C_4F_{10}**	**C_6F_{14}**
	P	A	A	A	A	A	A	A	A	A	A	A
Total HFCs and PFCs	**NA**	**NA**	**2.613**	**3.572**	**17.960**	**0.427**	**0.175**	**1.479**	**1.434**	**0.143**	**NE**	**NE**
C 3 Aluminum Production	NA	[b]	NO	NO	NO	NO	NO	NO	1.434	0.143	NE	NE
D 4 Semiconductor Manufacture [a]	NA	1.3	IE	NO	NO	NO	NO	NO	IE	IE	NO	NO
E 1 By-Product Emissions (HCFC-22 Production)	NA	[b]	2.570	NO	NO	NO	NO	NO	NO	NO	NO	NO
F Consumption of Halocarbons & SF_6	**25.7**	[b,c] **4.0**	**0.043**	**3.572**	**17.960**	**0.427**	**0.175**	**1.479**	**NE**	**NE**	**0.105**	**0.012**
1 Refrigeration and Air Conditioning Equipment	-	-	-	-	-	-	-	-	NE	NE	-	-
2 Foam Blowing	-	-	-	-	-	-	-	-	NE	NE	-	-
3 Fire Extinguishers	-	-	-	-	-	-	-	-	NE	NE	-	-
4 Aerosols	-	-	-	-	-	-	-	-	NE	NE	-	-
5 Solvents	-	-	-	-	-	-	-	-	NE	NE	-	-

"A" Actual emissions based on Tier 2 Approach.
"P" Potential emissions based on Tier 1 Approach.
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
[a] Includes gases such as HFC-23, CF_4, C_2F_6, SF_6, C_3F_8, and NF_3.
[b] Does not include emissions where estimates for individual gases were available for reporting.
[c] Includes HFC-152a, HFC-227ea, and PFC/PFPEs. PFC/PFPEs are a proxy for many diverse PFCs and perfluoropolyethers (PFPEs) that are employed in solvent applications. The GWP and atmospheric lifetime of this aggregate category is based upon that of C_6F_{14}.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 3 SECTORAL REPORT FOR SOLVENT AND OTHER PRODUCT USE (1997)
(Sheet 1 of 1)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)				
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**NO_x**	**CO**	**NMVOC**	**SO_2**
Total Solvent and Other Product Use	**3**	**6**	**5,882**	**1**
A Paint Application	2	1	2,713	0
B Degreasing and Dry Cleaning	0	1	801	0
C Chemical Products, Manufacture and Processing	IE	IE	IE	IE
D Graphic Arts	1	0	373	0
D Other Industrial	0	3	51	0
D Nonindustrial	0	0	1,943	NA

Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 4 SECTORAL REPORT FOR AGRICULTURE (1997)
(Sheet 1 of 2)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)					
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**
Total Agriculture	**9,448.6**	**913.56**	**37**	**843**	**NE**
A Enteric Fermentation	**5,962.6**	**NE**	**NE**	**NE**	**NE**
1 Cattle	5,691.6	NE	NE	NE	NE
2 Buffalo	NE	NE	NE	NE	NE
3 Sheep	88.0	NE	NE	NE	NE
4 Goats	60.9	NE	NE	NE	NE
5 Camels and Llamas	NE	NE	NE	NE	NE
6 Horses	11.5	NE	NE	NE	NE
7 Mules and Asses	NE	NE	NE	NE	NE
8 Swine	110.7	NE	NE	NE	NE
9 Poultry	NE	NE	NE	NE	NE
10 Other	NA	NA	NA	NA	NA
B Manure Management	**2,970.5**	**35.83**	**NE**	**NE**	**NE**
1 Cattle	1,023.0	15.40	NE	NE	NE
2 Buffalo	NE	NE	NE	NE	NE
3 Sheep	2.5	0.25	NE	NE	NE
4 Goats	0.8	0.05	NE	NE	NE
5 Camels and Llamas	NE	NE	NE	NE	NE
6 Horses	31.3	0.61	NE	NE	NE
7 Mules and Asses	NE	NE	NE	NE	NE
8 Swine	1,605.2	0.79	NE	NE	NE
9 Poultry	307.7	18.74	NE	NE	NE

Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 4 SECTORAL REPORT FOR AGRICULTURE (1997)
(Sheet 2 of 2)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)					
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**
B Manure Management (cont...)					
10 Anaerobic	IE	IE	NE	NE	NE
11 Liquid Systems	IE	IE	NE	NE	NE
12 Solid Storage and Dry Lot	IE	IE	NE	NE	NE
13 Other	NA	NA	NA	NA	NA
C Rice Cultivation	**475.4**	**NE**	**NE**	**NE**	**NE**
1 Irrigated	475.4	NE	NE	NE	NE
2 Rainfed	NO	NO	NO	NO	NO
3 Deep Water	NO	NO	NO	NO	NO
4 Other	NA	NA	NA	NA	NA
D Agricultural Soils	**NE**	**876.17**	**NE**	**NE**	**NE**
E Prescribed Burning of Savannas	**NO**	**NO**	**NO**	**NO**	**NO**
F Field Burning of Agricultural Residues	**40.1**	**1.56**	**37**	**843**	**NE**
1 Cereals	29.1	0.70	16	610	NE
2 Pulse	10.1	0.85	20	212	NE
3 Tuber and Root	NE	NE	NE	NE	NE
4 Sugar Cane	1.0	0.02	0	20	NE
5 Other	NA	NA	NA	NA	NA
G Other	**NA**	**NA**	**NA**	**NA**	**NA**

Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 5 SECTORAL REPORT FOR LAND-USE CHANGE AND FORESTRY (1997)
(Sheet 1 of 1)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)						
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CO_2 Emissions**	**CO_2 Removals**	**CH_4**	**N_2O**	**NO_x**	**CO**
Total Land-Use Change and Forestry	[a] **NA**	[a] **-764,683**	**NE**	**NE**	**NE**	**NE**
A Changes in Forest and Other Woody Biomass Stocks	[a] **NA**	[a] **-764,683**	**NE**	**NE**	**NE**	**NE**
1 Tropical Forests	NE	NE	NE	NE	NE	NE
2 Temperate Forests	NA	IE	NE	NE	NE	NE
3 Boreal Forests	NA	IE	NE	NE	NE	NE
4 Grasslands/Tundra	NE	NE	NE	NE	NE	NE
5 Other (General Forest Flux)	NA	-627,917	NE	NE	NE	NE
5 Other (Forest Products Flux)	NA	-65,523	NE	NE	NE	NE
5 Other (Landfill Carbon)	NA	-71,243	NE	NE	NE	NE
B Forest and Grassland Conversion	[a] **NE**	[a] **NE**	**NE**	**NE**	**NE**	**NE**
1 Tropical Forests	NE	NE	NE	NE	NE	NE
2 Temperate Forests	NE	NE	NE	NE	NE	NE
3 Boreal Forests	NE	NE	NE	NE	NE	NE
4 Grasslands/Tundra	NE	NE	NE	NE	NE	NE
5 Other	NA	NA	NA	NA	NA	NA
C Abandonment of Managed Lands	[a] **NE**	[a] **NE**	**NE**	**NE**	**NE**	**NE**
1 Tropical Forests	NE	NE	NE	NE	NE	NE
2 Temperate Forests	NE	NE	NE	NE	NE	NE
3 Boreal Forests	NE	NE	NE	NE	NE	NE
4 Grasslands/Tundra	NE	NE	NE	NE	NE	NE
5 Other	NA	NA	NA	NA	NA	NA
D CO_2 Emissions and Removals from Soil	[a] **NE**	[a] **NE**	**NE**	**NE**	**NE**	**NE**
E Other	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**

[a] Please do not provide an estimate of both CO_2 emissions and CO_2 removals. You should estimate "net" emissions of CO_2 and place a single number in either the CO_2 emissions or CO_2 removals column, as appropriate. Please note that for the purposes of reporting, the signs for uptake are always (-) and for emissions (+).
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 6 SECTORAL REPORT FOR WASTE (1997)
(Sheet 1 of 1)

SECTORAL REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)							
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CO_2 [a]**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**
Total Waste	**IE**	**11,807.7**	**28.19**	**94**	**1,127**	**407**	**45**
A Solid Waste Disposal on Land	**IE**	**11,646.4**	**NE**	**1**	**2**	**21**	**0**
1 Managed Waste Disposal on Land	IE	11,646.4	NE	1	2	21	0
2 Unmanaged Waste Disposal Sites	NE	NE	NE	NE	NE	NE	NE
3 Other	NA	NA	NA	NA	NA	NA	NA
B Wastewater Handling	**NE**	**161.3**	**[b]**	**0**	**0**	**61**	**1**
1 Industrial Wastewater	NE	NE	NE	0	0	12	0
2 Domestic and Commercial Wastewater	NE	161.3	[b]	0	0	49	0
3 Other	NA	NA	NA	NA	NA	NA	NA
C Waste Incineration	**IE**	**NE**	**0.83**	**92**	**1,124**	**246**	**44**
D Other	**NE**	**NE**	**27.36**	**1**	**1**	**79**	**0**
Transport, Storage, and Disposal Facility	NE	NE	NE	0	0	43	0
Other Waste	NE	NE	NE	1	1	36	0
Human sewage	NE	IE	27.36	NE	NE	NE	NE

[a] Note that CO_2 from waste disposal and incineration should only be included if it stems from non-biological or inorganic waste sources.
[b] Emissions from the human sewage portion of this source category is included under section D.
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 7A SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 1 of 3)

SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	HFCs		PFCs		SF_6	
									P	A	P	A	P	A
Total National Emissions and Removals	**5,455,553**	**-764,683**	**31,356.8**	**1,289.77**	**21,267**	**75,158**	**17,129**	**18,478**	**[a]**	**[a]**	**[a]**	**[a]**	**2.723**	**1.534**
1 Energy	**5,390,398**	**NA**	**10,025.1**	**256.24**	**20,352**	**65,493**	**8,217**	**17,258**						
A Fuel Combustion (Sectoral Approach)	5,375,164	NA	633.4	256.24	20,248	65,163	7,730	16,909						
1 Energy Industries	1,951,908	NA	24.4	26.79	5,605	368	46	11,868						
2 Manufacturing Industries & Construction	1,125,447	NA	151.4	17.92	2,967	1,007	197	3,053						
3 Transport	1,634,556	NA	242.4	207.40	10,519	60,794	6,949	1,252						
4 Other Sectors	616,927	NA	215.2	4.13	1,157	2,994	538	737						
5 Other (U.S. Territories)	46,326	NA	NE	NE	NE	NE	NE	NE						
B Fugitive Emissions from Fuels	15,235	NA	9,391.7		104	330	488	349						
1 Solid Fuels	NE	NA	3,274.1											
2 Oil and Natural Gas	15,235	NA	6,117.6		104	330	488	349						
2 Industrial Processes	**65,155**	**NA**	**75.4**	**91.77**	**781**	**7,689**	**2,622**	**1,175**	**[a]**	**[a]**	**[a]**	**[a]**	**2.723**	**1.534**
A Mineral Products	63,926	NA	NE	NE	IE	IE	IE	IE	NE	NE	NE	NE	NE	NE
B Chemical Industry	IE	NA	75.4	91.77	151	1,168	415	273	NE	NE	NE	NE	NE	NE
C Metal Production	IE	NA	NE	NE	93	2,237	66	501	NE	NE	[a]	[a]	0.460	0.460
D Other Production	1,229	NA	NE	NE	IE	IE	IE	IE	NA	NA	NA	NA	NA	NA
E Production of Halocarbons and SF_6	NE	NA	NE	NE	IE	IE	IE	IE	[a]	[a]	NE	NE	NE	NE
F Consumption of Halocarbons and SF_6	NA	NA	NA	NA	NA	NA	NA	NA	[a]	[a]	[a]	[a]	2.263	1.074
G Storage/Other/Miscellaneous	NA	NA	NA	NA	538	4,285	2,141	401	NA	NA	NA	NA	NA	NA

[a] Emissions of HFCs and PFCs are documented by gas in Table 2 Sheet 3.
"A" Actual emissions based on Tier 2 Approach.
"P" Potential emissions based on Tier 1 Approach.
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 7A SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 2 of 3)

SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)														
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CO_2 Emissions**	**CO_2 Removals**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**	**HFCs**		**PFCs**		**SF_6**	
									P	**A**	**P**	**A**	**P**	**A**
3 Solvent and Other Product Use	**NE**	**NE**	**NE**	**NE**	**3**	**6**	**5,882**	**1**						
4 Agriculture	**NE**	**NE**	**9,448.6**	**913.56**	**37**	**843**	**NE**	**NE**						
A Enteric Fermentation	NE	NE	5,962.6	NE	NE	NE	NE	NE						
B Manure Management	NE	NE	2,970.5	35.83	NE	NE	NE	NE						
C Rice Cultivation	NE	NE	475.4	NE	NE	NE	NE	NE						
D Agricultural Soils	[a] NE	[a] NE	NE	876.17	NE	NE	NE	NE						
E Prescribed Burning of Savannas	NO	NO	NO	NO	NO	NO	NO	NO						
F Field Burning of Agricultural Residues	NE	NE	40.1	1.56	37	843	NE	NE						
G Other	NA	NA	NA	NA	NA	NA	NA	NA						
5 Land-Use Change & Forestry	[a] **NA**	[a] **-764,683**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**						
A Changes in Forest and Other Woody Biomass Stocks	[a] NA	[a] -764,683	NE	NE	NE	NE	NE	NE						
B Forest and Grassland Conversion	[a] NE	[a] NE	NE	NE	NE	NE	NE	NE						
C Abandonment of Managed Lands	[a] NE	[a] NE	NE	NE	NE	NE	NE	NE						
D CO_2 Emissions and Removals from Soil	[a] NE	[a] NE	NE	NE	NE	NE	NE	NE						
E Other	NA	NA	NA	NA	NA	NA	NE	NE						
6 Waste	**IE**	**IE**	**11,807.7**	**28.19**	**94**	**1,127**	**407**	**45**						
A Solid Waste Disposal on Land	IE	IE	11,646.4	NE	1	2	21	0						
B Wastewater Handling	NE	NE	161.3	[b]	0	0	61	1						
C Waste Incineration	IE	NE	NE	0.83	92	1,124	246	44						
D Other	NE	NE	NE	27.36	1	1	79	0						
7 Other	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**						

[a] Please do not provide an estimate of both CO_2 emissions and CO_2 removals. You should estimate "net" emissions of CO_2 and place a single number in either the CO_2 emissions or CO_2 removals column, as appropriate. Please note that for the purposes of reporting, the signs for uptake are always (-) and for emissions (+).
[b] Emissions from the human sewage portion of this source category is included under section 6.D.
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 7A SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 3 of 3)

SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)														
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	**CO_2 Emissions**	**CO_2 Removals**	**CH_4**	**N_2O**	**NO_x**	**CO**	**NMVOC**	**SO_2**	**HFCs**		**PFCs**		**SF_6**	
									P	**A**	**P**	**A**	**P**	**A**
Memo Items [a]														
International Bunkers	**97,542**	**NE**	**1.8**	**2.76**	**1,448**	**111**	**46**	**NE**						
Aviation	50,974	NE	1.4	1.62	202	84	13	NE						
Marine	46,568	NE	0.4	1.15	1,246	27	33	NE						
CO_2 Emissions from Biomass	**216,561**													

[a] Not included in totals.
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 7B SHORT SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 1 of 1)

SHORT SUMMARY REPORT FOR NATIONAL GREENHOUSE GAS INVENTORIES (Gg)																
GREENHOUSE GAS SOURCE AND SINK CATEGORIES		CO_2 Emissions	CO_2 Removals	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	HFCs		PFCs		SF_6	
										P	A	P	A	P	A
Total National Emissions and Removals		**5,455,553**	**-764,683**	**31,356.8**	**1,289.77**	**21,267**	**75,158**	**17,129**	**18,478**	**[a]**	**[a]**	**[a]**	**[a]**	**2.723**	**1.534**
1 Energy	Reference Approach [b]	**5,415,400**													
	Sectoral Approach [b]	**5,390,398**	**NA**	**10,025.1**	**256.24**	**20,352**	**65,493**	**8,217**	**17,258**						
A Fuel Combustion		5,375,164	NA	633.4	256.24	20,248	65,163	7,730	16,909						
B Fugitive Emissions from Fuels		15,235	NA	9,391.7		104	330	488	349						
2 Industrial Processes		**65,155**	**NA**	**75.4**	**91.77**	**781**	**7,689**	**2,622**	**1,175**	**[a]**	**[a]**	**[a]**	**[a]**	**2.723**	**1.534**
3 Solvent and Other Product Use		**NE**	**NE**	**NE**	**NE**	**3**	**6**	**5,882**	**1**						
4 Agriculture		**NE**	**NE**	**9,448.6**	**913.56**	**37**	**843**	**NE**	**NE**						
5 Land-Use Change & Forestry		[c] **NA**	[c] **-764,683**	**NE**	**NE**	**NE**	**NE**	**NE**	**NE**						
6 Waste		**IE**	**IE**	**11,807.7**	**28.19**	**94**	**1,127**	**407**	**45**						
7 Other		**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**						
Memo Items:															
International Bunkers		**97,542**	**NE**	**1.8**	**2.76**	**1,448**	**111**	**46**	**NE**						
Aviation		50,974	NE	1.4	1.62	202	84	13	NE						
Marine		46,568	NE	0.4	1.15	1,246	27	33	NE						
CO_2 Emissions from Biomass		**216,561**													

[a] Emissions of HFCs and PFCs are documented by gas in Table 2 Sheet 3.
[b] For verification purposes, countries are asked to report the results of their calculations using the Reference Approach and explain any differences with the Sectoral Approach. Do not include the results of both the Reference Approach and the Sectoral Approach in national totals.
[c] Please do not provide an estimate of both CO_2 emissions and CO_2 removals. You should estimate "net" emissions of CO_2 and place a single number in either the CO_2 emissions or CO_2 removals column, as appropriate. Please note that for the purposes of reporting, the signs for uptake are always (-) and for emissions (+).
Note: Totals may not equal sum of components due to independent rounding.
- Value is included in an aggregate figure, but not estimated separately.
"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)

TABLE 8A OVERVIEW TABLE FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 1 of 6)

OVERVIEW TABLE

GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2		CH_4		N_2O		NO_x		CO		NMVOC		SO_2	
	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality
Total National Emissions and Removals														
1 Energy														
A Fuel Combustion Activities														
Reference Approach	ALL	H												
Sectoral Approach	ALL	H	ALL	M	ALL	L	ALL	M	ALL	M	ALL	L	ALL	M
1 Energy Industries	ALL	H	ALL	M	ALL	L	ALL	M	ALL	M	ALL	L	ALL	M
2 Manufacturing Industries & Construction	ALL	H	ALL	M	ALL	L	ALL	M	ALL	M	ALL	L	ALL	M
3 Transport	ALL	H	ALL	M	PART	L	ALL	H	ALL	H	ALL	L	ALL	M
4 Other Sectors	ALL	H	ALL	L	ALL	L	ALL	M	ALL	M	ALL	L	IE	
5 Other (U.S. Territories)	ALL	M	NE		NE		NE		NE		NE		NE	
B Fugitive Emissions from Fuels														
1 Solid Fuels	NE		PART [b]	M	NE		NE		NE		NE		NE	
2 Oil and Natural Gas	PART [a]	M	ALL	L	NE		ALL	M	ALL	M	ALL	L	ALL	M
2 Industrial Processes														
A Mineral Products	ALL	H	NE		NE		IE		IE		IE		IE	
B Chemical Industry	ALL	M	PART [c]	M	ALL	H	ALL	M	ALL	M	ALL	M	ALL	M
C Metal Production	IE		NE		NE		ALL	M	ALL	M	ALL	M	ALL	M
D Other Production	NA		NA		NA		IE		IE		IE		IE	
E Production of Halocarbons & SF_6	NO		NO		NO		IE		IE		IE		IE	

"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)
PART (Partly estimated)
ALL (Full estimate of all possible sources)

Quality:
H = High Confidence in Estimation
M = Medium Confidence in Estimation
L = Low Confidence in Estimation

Disaggregation:
1 = Total emissions estimated
2 = Sectoral split
3 = Subsectoral split

Documentation:
H = High (all background information included)
M = Medium (some background information included)
L = Low (only emission estimates included)

[a] Estimate excludes geologic carbon dioxide deposits released during petroleum and natural gas production.
[b] Does not include abandoned coal mines.
[c] Not all potential sources were included. See sources excluded annex.
[d] Only HCFC-22 production included.

TABLE 8A OVERVIEW TABLE FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 2 of 6)

OVERVIEW TABLE								
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	HFCs		PFCs		SF_6		Documen-tation	Disaggre-gation
	Estimate	Quality	Estimate	Quality	Estimate	Quality		
Total National Emissions and Removals								
1 Energy								
A Fuel Combustion Activities								
Reference Approach							H	1
Sectoral Approach	NO		NO		NO		H	3
1 Energy Industries	NO		NO		NO		H	1
2 Manufacturing Industries & Construction	NO		NO		NO		H	1
3 Transport	NO		NO		NO		H	2
4 Other Sectors	NO		NO		NO		H	1
5 Other (U.S. Territories)	NO		NO		NO		H	1
B Fugitive Emissions from Fuels								
1 Solid Fuels	NO		NO		NO		H	3
2 Oil and Natural Gas	NO		NO		NO		H	3
2 Industrial Processes								
A Mineral Products	NE		NE		NE		H	3
B Chemical Industry	NE		NE		NE		H	3
C Metal Production	NE		ALL	H	ALL	M	M	3
D Other Production	NA		NA		NA			
E Production of Halocarbons & SF_6	PART [d]	H	NE		NE		M	2

"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)
PART (Partly estimated)
ALL (Full estimate of all possible sources)
[a] Estimate excludes geologic carbon dioxide deposits released during petroleum and natural gas production.
[b] Does not include abandoned coal mines.
[c] Not all potential sources were included. See sources excluded annex.
[d] Only HCFC-22 production included.

Quality:
H = High Confidence in Estimation
M = Medium Confidence in Estimation
L = Low Confidence in Estimation

Disaggregation:
1 = Total emissions estimated
2 = Sectoral split
3 = Subsectoral split

Documentation:
H = High (all background information included)
M = Medium (some background information included)
L = Low (only emission estimates included)

TABLE 8A OVERVIEW TABLE FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 3 of 6)

OVERVIEW TABLE															
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2		CH_4		N_2O		NO_x		CO		NMVOC		SO_2	
	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality
Industrial Processes (cont...)														
F Consumption of Halocarbons & SF_6														
Potential [a]	NA		NA		NA		NA		NA		NA		NA	
Actual [b]	NA		NA		NA		NA		NA		NA		NA	
G Storage/Other/Miscellaneous	NA		NA		NA		ALL	M	ALL	M	ALL	L	ALL	M
3 Solvent and Other Product Use	NE		NE		NE		ALL	M	ALL	M	ALL	M	ALL	M
4 Agriculture														
A Enteric Fermentation	NE		ALL	M	NE		NE		NE		NE		NE	
B Manure Management	NE		ALL	M	ALL	L	NE		NE		NE		NE	
C Rice Cultivation	NE		ALL	L	NE		NE		NE		NE		NE	
D Agricultural Soils	NE		NE		ALL	L	NE		NE		NE		NE	
E Prescribed Burning of Savannas	NO		NO		NO		NO		NO		NO		NO	
F Field Burning of Agricultural Residues	NE		ALL	L	ALL	L	ALL	L	ALL	L	NE		NE	
G Other	NA		NA		NA		NA		NA		NA		NA	
5 Land-Use Change & Forestry														
A Changes in Forest and Other Woody Biomass Stocks	PART [c]	M	NE		NE		NE		NE		NE		NE	
B Forest and Grassland Conversion	NE		NE		NE		NE		NE		NE		NE	

"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)
PART (Partly estimated)
ALL (Full estimate of all possible sources)
[a] Potential emissions based on Tier 1 Approach.
[b] Actual emissions based on Tier 2 Approach.
[c] Estimate does not include Alaska, Hawaii, or U.S. Territories.

Quality:
H = High Confidence in Estimation
M = Medium Confidence in Estimation
L = Low Confidence in Estimation

Disaggregation:
1 = Total emissions estimated
2 = Sectoral split
3 = Subsectoral split

Documentation:
H = High (all background information included)
M = Medium (some background information included)
L = Low (only emission estimates included)

TABLE 8A OVERVIEW TABLE FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 4 of 6)

OVERVIEW TABLE								
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	HFCs		PFCs		SF_6		Documen-tation	Disaggre-gation
	Estimate	Quality	Estimate	Quality	Estimate	Quality		
Industrial Processes (cont...)								
F Consumption of Halocarbons & SF_6								
Potential [a]	ALL	M	ALL	M	ALL	M	M	2
Actual [b]	ALL	M	ALL	M	ALL	M	M	2
G Storage/Other/Miscellaneous	NA		NA		NA		M	2
3 Solvent and Other Product Use	NA		NA		NA		M	3
4 Agriculture								
A Enteric Fermentation	NA		NA		NA		H	3
B Manure Management	NA		NA		NA		H	3
C Rice Cultivation	NA		NA		NA		H	3
D Agricultural Soils	NA		NA		NA		H	3
E Prescribed Burning of Savannas	NA		NA		NA			
F Field Burning of Agricultural Residues	NA		NO		NO		H	3
G Other	NA		NA		NA			
5 Land-Use Change & Forestry								
A Changes in Forest and Other Woody Biomass Stocks	NA		NA		NA		M	2
B Forest and Grassland Conversion	NA		NA		NA			

"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)
PART (Partly estimated)
ALL (Full estimate of all possible sources)
[a] Potential emissions based on Tier 1 Approach.
[b] Actual emissions based on Tier 2 Approach.
[c] Estimate does not include Alaska, Hawaii, or U.S. Territories.

Quality:
H = High Confidence in Estimation
M = Medium Confidence in Estimation
L = Low Confidence in Estimation

Disaggregation:
1 = Total emissions estimated
2 = Sectoral split
3 = Subsectoral split

Documentation:
H = High (all background information included)
M = Medium (some background information included)
L = Low (only emission estimates included)

TABLE 8A OVERVIEW TABLE FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 5 of 6)

OVERVIEW TABLE														
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	CO_2		CH_4		N_2O		NO_x		CO		NMVOC		SO_2	
	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality	Estimate	Quality
5 Land-Use Change & Forestry (cont....)														
C Abandonment of Managed Lands	NE		NE		NE		NE		NE		NE		NE	
D CO_2 Emissions and Removals from Soil	PART [a]	L	NE		NE		NE		NE		NE		NE	
E Other	NA		NA		NA		NA		NA		NA		NA	
6 Waste														
A Solid Waste Disposal on Land	IE		ALL	M	NE		ALL	L	ALL	L	ALL	L	ALL	L
B Wastewater Handling	NE		PART [b]	L	PART [c]	L	ALL	L	ALL	L	ALL	L	ALL	L
C Waste Incineration	IE		NE		ALL	L	ALL	L	ALL	L	ALL	L	ALL	L
D Other	NE		NE		ALL	L	ALL	L	ALL	L	ALL	L	ALL	L
7 Other	NA		NA		NA		NA		NA		NA		NA	
Memo Items:														
International Bunkers														
Aviation	ALL	M	NE		NE		IE		IE		IE		IE	
Marine	ALL	M	NE		NE		IE		IE		IE		IE	
CO_2 Emissions from Biomass	ALL	M												

"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)
PART (Partly estimated)
ALL (Full estimate of all possible sources)
[a] Non-forest soils are not included in this estimate.
[b] Estimate does not include emissions from industrial wastewater.
[c] Includes emissions from human sewage only

Quality:
H = High Confidence in Estimation
M = Medium Confidence in Estimation
L = Low Confidence in Estimation

Disaggregation:
1 = Total emissions estimated
2 = Sectoral split
3 = Subsectoral split

Documentation:
H = High (all background information included)
M = Medium (some background information included)
L = Low (only emission estimates included)

TABLE 8A OVERVIEW TABLE FOR NATIONAL GREENHOUSE GAS INVENTORIES (1997)
(Sheet 6 of 6)

OVERVIEW TABLE								
GREENHOUSE GAS SOURCE AND SINK CATEGORIES	HFCs		PFCs		SF_6		Documen-tation	Disaggre-gation
	Estimate	Quality	Estimate	Quality	Estimate	Quality		
5 Land-Use Change & Forestry (cont....)								
C Abandonment of Managed Lands	NA		NA		NA			
D CO_2 Emissions and Removals from Soil	NA		NA		NA		H	2
E Other	NA		NA		NA			
6 Waste								
A Solid Waste Disposal on Land	NO		NO		NO		H	2
B Wastewater Handling	NO		NO		NO		H	2
C Waste Incineration	NO		NO		NO		H	1
D Other	NO		NO		NO		H	1
7 Other	NA		NA		NA			
Memo Items:								
International Bunkers								
Aviation	NO		NO		NO		H	1
Marine	NO		NO		NO		H	1
CO_2 Emissions from Biomass							H	2

"0" (Estimate for source is insignificant or close to zero)
NA (Not applicable to source category)
NE (Not estimated)
NO (Not occurring in the United States)
IE (Estimated but included elsewhere)
PART (Partly estimated)
ALL (Full estimate of all possible sources)
[a] Non-forest soils are not included in this estimate.
[b] Estimate does not include emissions from industrial wastewater.
[c] Includes emissions from human sewage only

Quality:
H = High Confidence in Estimation
M = Medium Confidence in Estimation
L = Low Confidence in Estimation

Disaggregation:
1 = Total emissions estimated
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Documentation:
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L = Low (only emission estimates included)

Annex O

IPCC Reference Approach for Estimating CO_2 Emissions from Fossil Fuel Combustion

It is possible to estimate carbon emissions from fossil fuel consumption using alternative methodologies and different data sources than those described in Annex A. For example, the IPCC requires countries in addition to their "bottom-up" sectoral methodology to complete a "top-down" Reference Approach for estimating carbon dioxide emissions from fossil fuel combustion. Section 1.3 of the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reporting Instructions* states, "If a detailed, Sectoral Approach for energy has been used for the estimation of CO_2 from fuel combustion you are still asked to complete…the Reference Approach…for verification purposes" (IPCC/UNEP/OECD/IEA 1997). This reference method estimates fossil fuel consumption by adjusting national aggregate fuel production data for imports, exports, and stock changes rather than relying on end-user consumption surveys. The basic principle is that once carbon-based fuels are brought into a national economy, they are either saved in some way (e.g., stored in products, kept in fuel stocks, or left unoxidized in ash) or combusted, and therefore the carbon in them is oxidized and released into the atmosphere. Accounting for actual consumption of fuels at the sectoral or sub-national level is not required. The following discussion provides the detailed calculations for estimating CO_2 emissions from fossil fuel combustion from the United States using the IPCC-recommended Reference Approach.

Step 1: Collect and Assemble Data in Proper Format

To ensure the comparability of national inventories, the IPCC has recommended that countries report energy data using the International Energy Agency (IEA) reporting convention. National energy statistics were collected in physical units from several DOE/EIA documents in order to obtain the necessary data on production, imports, exports, and stock changes.[17] These data are presented in Table O-1.

The carbon content of fuel varies with the fuel's heat content. Therefore, for an accurate estimation of CO_2 emissions, fuel statistics should be provided on an energy content basis (e.g., BTU's or joules). Because detailed fuel production statistics are typically provided in physical units (as in Table O-1), they were converted to units of energy before carbon emissions were calculated. Fuel statistics were converted to their energy equivalents by using conversion factors provided by DOE/EIA. These factors and their data sources are displayed in Table O-2. The resulting fuel data are provided in Table O-3.

Step 2: Estimate Apparent Fuel Consumption

The next step of the IPCC Reference Approach is to estimate "apparent consumption" of fuels within the country. This requires a balance of primary fuels produced, plus imports, minus exports, and adjusting for stock changes. In this way, carbon enters an economy through energy production and imports (and decreases in fuel stocks) and is transferred out of the country through exports (and increases in fuel stocks). Thus, apparent consumption of primary fuels (including crude oil, natural gas liquids, anthracite, bituminous, subbituminous and lignite coal, and natural gas) can be calculated as follows:

$$\textit{Production} + \textit{Imports} - \textit{Exports} - \textit{Stock Change}$$

[17] For the United States, national aggregate energy statistics typically exclude data on the U.S. territories. As a result, national statistics were adjusted to include U.S. territories data. The territories include Puerto Rico, U.S. Virgin Islands, Guam, American Samoa, Wake Island, and U.S. Pacific Islands. Consumption data were used for the territories because they are thought to be more reliable than production, import, export, and stock change data.

Flows of secondary fuels (e.g., gasoline, residual fuel, coke) should be added to primary apparent consumption. The production of secondary fuels, however, should be ignored in the calculations of apparent consumption since the carbon contained in these fuels is already accounted for in the supply of primary fuels from which they were derived (e.g., the estimate for apparent consumption of crude oil already contains the carbon from which gasoline would be refined). Flows of secondary fuels should therefore be calculated as follows:

Imports - Exports - Stock Change

Note that this calculation can result in negative numbers for apparent consumption. This is a perfectly acceptable result since it merely indicates a net export or stock increase in the country of that fuel when domestic production is not considered.

The IPCC Reference Approach calls for estimating apparent fuel consumption before converting to a common energy unit. However, certain primary fuels in the United States (e.g., natural gas and steam coal) have separate conversion factors for production, imports, exports, and stock changes. In these cases, it is not appropriate to multiply apparent consumption by a single conversion factor since each of its components have different heat contents. Therefore, United States fuel statistics were converted to their heat equivalents before estimating apparent consumption. The energy value of bunker fuels used for international transport activities was subtracted before computing energy totals.[18] Results are provided in Table O-3.

Step 3: Estimate Carbon Emissions

Once apparent consumption is estimated, the remaining calculations are virtually identical to those for the "bottom-up" Sectoral Approach (see Annex A). That is:

- Potential carbon emissions were estimated using fuel-specific carbon coefficients (see Table O-4).[19]
- The carbon sequestered in non-energy uses of fossil fuels (e.g., plastics or asphalt) was then estimated and subtracted from the total amount of carbon (see Table O-5).
- Finally, to obtain actual carbon emissions, net carbon emissions were adjusted for any carbon that remained unoxidized as a result of incomplete combustion (e.g., carbon contained in ash or soot).[20]

Step 4: Convert to CO_2 Emissions

Because the IPCC reporting guidelines recommend that countries report greenhouse gas emissions on a full molecular weight basis, the final step in estimating CO_2 emissions from fossil fuel consumption was converting from units of carbon to units of CO_2. Actual carbon emissions were multiplied by the molecular-to-atomic weight ratio of CO_2 to carbon (44/12) to obtain total carbon dioxide emitted from fossil fuel combustion in teragrams (Tg). The results are contained in Table O-6.

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[18] Bunker fuels refer to quantities of fuels used for international transportation. The IPCC methodology accounts for these fuels as part of the energy balance of the country in which they were delivered to end-users. Carbon dioxide emissions from the combustion of these fuels were estimated separately and were not included in U.S. national totals. This is done to ensure that all fuel is accounted for in the methodology and so that the IPCC is able to prepare global emission estimates.

[19] Carbon coefficients from EIA were used wherever possible. Because EIA did not provide coefficients for coal, the IPCC-recommended emission factors were used in the top-down calculations for these fuels. See notes in Table O-4 for more specific source information.

[20] For the portion of carbon that is unoxidized during coal combustion, the IPCC suggests a global average value of 2 percent. However, because combustion technologies in the United States are more efficient, the United States inventory uses 1 percent in its calculations for petroleum and coal and 0.5 percent for natural gas.

Comparison Between Sectoral and Reference Approaches

These two alternative approaches can both produce reliable estimates that are comparable within a few percent. The major difference between methodologies employed by each approach lies in the energy data used to derive carbon emissions (i.e., the actual reported consumption for the Sectoral Approach versus apparent consumption derived for the Reference Approach). In theory, both approaches should yield identical results. In practice, however, slight discrepancies occur. For the United States, these differences are discussed below.

Differences in Total Amount of Energy Consumed

Table O-7 and Table O-9[21] summarize the differences between the Reference and Sectoral approaches in estimating total energy consumption in the United States. Although theoretically the two methods should arrive at the same estimate for U.S. energy consumption, the Reference Approach provides an energy total that is 0.4 percent lower than the Sectoral Approach for 1997. The greatest difference lies in the higher estimate of petroleum consumption with the Sectoral Approach (1.0 percent).

There are several potential sources for the discrepancies in consumption estimates:

- *Product Definitions*. The fuel categories in the Reference Approach are different from those used in the Sectoral Approach, particularly for petroleum. For example, the Reference Approach estimates apparent consumption for crude oil. Crude oil is not typically consumed directly, but refined into other products. As a result, the United States does not focus on estimating the energy content of crude oil, but rather estimating the energy content of the various products resulting from crude oil refining. The United States does not believe that estimating apparent consumption for crude oil, and the resulting energy content of the crude oil, is the most reliable method for the United States to estimate its energy consumption. Other differences in product definitions include using sector-specific coal statistics in the Sectoral Approach (i.e., residential, commercial, industrial coking, industrial other, and transportation coal), while the Reference Approach characterizes coal by rank (i.e. anthracite, bituminous, etc.). Also, the liquefied petroleum gas (LPG) statistics used in the bottom-up calculations are actually a composite category composed of natural gas liquids (NGL) and LPG.
- Heat Equivalents. It can be difficult to obtain heat equivalents for certain fuel types, particularly for categories such as "crude oil" where the key statistics are derived from thousands of producers in the United States and abroad. For heat equivalents by coal rank, it was necessary to refer back to EIA's *State Energy Data Report 1992* (1994) because this information is no longer published.
- *Possible inconsistencies in U.S. Energy Data*. The United States has not focused its energy data collection efforts on obtaining the type of aggregated information used in the Reference Approach. Rather, the United States believes that its emphasis on collection of detailed energy consumption data is a more accurate methodology for the United States to obtain reliable energy data. Therefore, top-down statistics used in the Reference Approach may not be as accurately collected as bottom-up statistics applied to the Sectoral Approach.
- *Balancing Item.* The Reference Approach uses *apparent* consumption estimates while the Sectoral Approach uses *reported* consumption estimates. While these numbers should be equal, there always seems to be a slight difference that is often accounted for in energy statistics as a "balancing item."

Differences in Estimated CO_2 Emissions

Given these differences in energy consumption data, the next step for each methodology involved estimating emissions of CO_2. Table O-8 summarizes the differences between the two methods in estimated carbon emissions for 1997. Although complete data and calculations are not presented, comparison tables are also presented for 1996 emissions in Table O-10.

As shown previously, the Sectoral Approach resulted in a 0.4 percent higher estimate of energy consumption in the United States than the Reference Approach, but the resulting emissions estimate for the Reference Approach is 0.8 percent higher. While both methods' estimates of natural gas emissions are almost exactly the same, coal and

[21] Although complete energy consumption data and calculations are not presented, comparison tables are also presented for 1996.

petroleum emission estimates from the Reference Approach are higher than the Sectoral Approach. Potential reasons for these patterns may include:

- *Product Definitions.* Coal data is aggregated differently in each methodology, as noted above, with United States coal data typically collected in the format used for the Sectoral Approach. This results in more accurate estimates than in the Reference Approach. Also, the Reference Approach relies on a "crude oil" category for determining petroleum-related emissions. Given the many sources of crude oil in the United States, it is not an easy matter to track potential differences in carbon content between different sources of crude, particularly since information on the carbon content of crude oil is not regularly collected.
- *Carbon Coefficients.* The Reference Approach relies on several default carbon coefficients provided by IPCC (IPCC/UNEP/OECD/IEA 1997), while the Sectoral Approach uses category-specific coefficients that are likely to be more accurate. Also, as noted above, the carbon coefficient for crude oil is not an easy value to obtain given the many sources and grades of crude oil consumed in the United States.

Although the two approaches produce similar results, the United States believes that the “bottom-up” Sectoral Approach provides a more accurate assessment of CO_2 emissions at the fuel level. This improvement in accuracy is largely a result of the data collection techniques used in the United States, where there has been more emphasis on obtaining the detailed products-based information used in the Sectoral Approach than obtaining the aggregated energy flow data used in the Reference Approach. The United States believes that it is valuable to understand both methods.

References

EIA (1998a) *Annual Energy Review 1997*, DOE/EIA- 0384(97)-annual, Energy Information Administration, U.S. Department of Energy, Washington, DC.

EIA (1998b) *Coal Industry Annual – 1997*, DOE/EIA 0584(97)-annual, Energy Information Administration, U.S. Department of Energy, Washington, DC.

EIA (1998c) *Emissions of Greenhouse Gases in the United States 1997*, DOE/EIA 0573(97)-annual, Energy Information Administration, U.S. Department of Energy, Washington, DC.

EIA (1998d) *Monthly Energy Review*, DOE/EIA 0035(98)-monthly, Energy Information Administration, U.S. Department of Energy, Washington, DC. November.

EIA (1998e) *Petroleum Supply Annual – 1997*, DOE/EIA 0340(97)-annual, Energy Information Administration, U.S. Department of Energy, Washington, DC, Volume I.

EIA (1994*) State Energy Data Report 1992*, DOE/EIA 0214(92)-annual, Energy Information Administration, U.S. Department of Energy, Washington, DC.

IPCC/UNEP/OECD/IEA (1997) *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, Paris: Intergovernmental Panel on Climate Change, United Nations Environment Programme, Organization for Economic Co-Operation and Development, International Energy Agency.

Table O-1: 1997 U.S. Energy Statistics (physical units)

Fuel Category (Units)	Fuel Type	Production	Imports	Exports	Stock Change	Bunkers	U.S. Territories
Solid Fuels (1000 Short Tons)	Anthracite Coal	4,692	[1]	[1]	[1]		
	Bituminous Coal	653,828	[1]	[1]	[1]		
	Sub-bituminous Coal	345,071	[1]	[1]	[1]		
	Lignite	86,341	[1]	[1]	[1]		
	Coke		1,565	832	(29)		
	Unspecified Coal		7,487	83,545	(10,817)		480
Gas Fuels (Million Cubic Feet)	Natural Gas	19,152,427	2,972,368	157,463	(26,906)		
Liquid Fuels (Thousand Barrels)	Crude Oil	2,354,831	3,002,299	39,308	18,450		
	Nat Gas Liquids and LRGs	663,266	74,831	20,882	2,617		2,791
	Other Liquids	78,471	224,060	9,265	5,576		
	Motor Gasoline		112,837	49,878	9,367		27,547
	Aviation Gasoline		41	-	(575)		
	Kerosene		570	138	273		12,949
	Jet Fuel		33,109	12,763	4,178	128,123	
	Distillate Fuel		83,102	55,507	11,698	13,637	19,371
	Residual Fuel		70,829	43,782	(5,458)	83,221	27,912
	Naptha for petrochemical feedstocks		18,681	-	35		
	Petroleum Coke		386	111,615			
	Other Oil for petrochemical feedstocks		69,086	-	772		
	Special Napthas		2,709	7,849	281		
	Lubricants		4,026	11,275	215		-
	Waxes		441	993	(80)		
	Asphalt/Road Oil		11,862	2,879	1,619		
	Still Gas		-	-	-		
	Misc. Products		101	125	618		20,005

[1] Included in Unspecified Coal

Data Sources: Solid Fuels - EIA Coal Industry Annual 1997; Gas Fuels - EIA Annual Energy Review 1997; Liquid Fuels - EIA Petroleum Supply Annual 1997

Table O-2: Conversion Factors to Energy Units (heat equivalents)

Fuel Category (Units)	Fuel Type	Production	Imports	Exports	Stock Change	Bunkers	U.S. Territories
Solid Fuels (Million Btu/Short Ton)	Anthracite Coal	22.573					
	Bituminous Coal	23.89					
	Sub-bituminous Coal	17.14					
	Lignite	12.866					
	Coke		24.8	24.8	24.8		
	Unspecified		25.000	26.174	21.287		21.287
Natural Gas (BTU/Cubic Foot)		1,027	1,022	1,011	1,027		
Liquid Fuels (Million Btu/Barrel)	Crude Oil	5.800	5.935	5.800	5.800	5.800	5.800
	Nat Gas Liquids and LRGs	3.777	3.777	3.777	3.777	3.777	3.777
	Other Liquids	5.825	5.825	5.825	5.825	5.825	5.825
	Motor Gasoline		5.253	5.253	5.253	5.253	5.253
	Aviation Gasoline		5.048	5.048	5.048	5.048	5.048
	Kerosene		5.67	5.67	5.67	5.67	5.67
	Jet Fuel		5.67	5.67	5.67	5.67	5.67
	Distillate Fuel		5.825	5.825	5.825	5.825	5.825
	Residual Oil		6.287	6.287	6.287	6.287	6.287
	Naptha for petrochemical feedstocks		5.248	5.248	5.248	5.248	5.248
	Petroleum Coke		6.024	6.024	6.024	6.024	6.024
	Other Oil for petrochemical feedstocks		5.825	5.825	5.825	5.825	5.825
	Special Napthas		5.248	5.248	5.248	5.248	5.248
	Lubricants		6.065	6.065	6.065	6.065	6.065
	Waxes		5.537	5.537	5.537	5.537	5.537
	Asphalt/Road Oil		6.636	6.636	6.636	6.636	6.636
	Still Gas		6.000	6.000	6.000	6.000	6.000
	Misc. Products		5.796	5.796	5.796	5.796	5.796

Data Sources: Coal and lignite production - EIA State Energy Data Report 1992; Coke - EIA Monthly Energy Review, November 1998; Unspecified Solid Fuels - EIA Monthly Energy Review, November 1998; Natural Gas - EIA Monthly Energy Review, November 1998; Crude Oil - EIA Monthly Energy Review, November 1998; Natural Gas Liquids and LRGs - EIA Petroleum Supply Annual 1997; all other Liquid Fuels - EIA Monthly Energy Review, November 1998

Table O-3: 1997 Apparent Consumption of Fossil Fuels (TBtu)

Fuel Category	Fuel Type	Production	Imports	Exports	Stock Change	Bunkers	U.S. Territories	Apparent Consumption
Solid Fuels	Anthracite Coal	105.9					-	**105.9**
	Bituminous Coal	15,620.0					-	**15,620.0**
	Sub-bituminous Coal	5,914.5					-	**5,914.5**
	Lignite	1,110.9					-	**1,110.9**
	Coke	-	38.8	20.6	(0.7)		-	**18.9**
	Unspecified	-	187.2	2,186.7	(230.3)		10.2	**(1,759.1)**
Gas Fuels	Natural Gas	19,669.5	3,037.8	159.2	(27.6)		-	**22,575.7**
Liquid Fuels	Crude Oil	13,658.0	17,818.6	228.0	107.0	-	-	**31,141.7**
	Nat Gas Liquids and LRGs	2,505.2	282.6	78.9	9.9	-	10.5	**2,709.6**
	Other Liquids	457.1	1,305.1	54.0	32.5	-	-	**1,675.8**
	Motor Gasoline	-	592.7	262.0	49.2	-	144.7	**426.2**
	Aviation Gasoline	-	0.2	-	(2.9)	-	-	**3.1**
	Kerosene	-	3.2	0.8	1.5	-	73.4	**74.3**
	Jet Fuel	-	187.7	72.4	23.7	726.5	-	**(634.8)**
	Distillate Fuel	-	484.1	323.3	68.1	79.4	112.8	**126.0**
	Residual Oil	-	445.3	275.3	(34.3)	523.2	175.5	**(143.4)**
	Naptha for petrochemical feedstocks	-	98.0	-	0.2	-	-	**97.9**
	Petroleum Coke	-	2.3	672.4	16.6	-	-	**(686.7)**
	Other Oil for petrochemical feedstocks	-	402.4	-	4.5	-	-	**397.9**
	Special Napthas	-	14.2	41.2	1.5	-	-	**(28.4)**
	Lubricants	-	24.4	68.4	1.3	-	-	**(45.3)**
	Waxes	-	2.4	5.5	(0.4)	-	-	**(2.6)**
	Asphalt/Road Oil	-	78.7	19.1	10.7	-	-	**48.9**
	Still Gas	-	-	-	-	-	-	**0.0**
	Misc. Products	-	0.6	0.7	3.6	-	115.9	**112.2**
Total		59,041.1	25,006.6	4,468.4	34.1	988.2	643.2	**78,859.3**

Note: Totals may not sum due to independent rounding.

Table O-4: 1997 Potential Carbon Emissions

Fuel Category	Fuel Type	Apparent Consumption (QBtu)	Carbon Coefficients (MMTCE/QBtu)	Potential Carbon Emissions (MMTCE)
Solid Fuels	Anthracite Coal	0.106	26.86	**2.8**
	Bituminous Coal	15.620	25.86	**403.9**
	Sub-bituminous Coal	5.915	26.26	**155.3**
	Lignite	1.111	27.66	**30.7**
	Coke	0.019	25.56	**0.5**
	Unspecified	(1.759)	25.74	**(45.3)**
Gas Fuels	Natural Gas	22.576	14.47	**326.7**
Liquid Fuels	Crude Oil	31.142	20.23	**630.0**
	Nat Gas Liquids and LRGs	2.710	16.99	**46.0**
	Other Liquids	1.676	20.23	**33.9**
	Motor Gasoline	0.426	19.38	**8.3**
	Aviation Gasoline	0.003	18.87	**0.1**
	Kerosene	0.074	19.72	**1.5**
	Jet Fuel	(0.635)	19.33	**(12.3)**
	Distillate Fuel	0.126	19.95	**2.5**
	Residual Oil	(0.143)	21.49	**(3.1)**
	Naptha for petrochemical feedstocks	0.098	18.14	**1.8**
	Petroleum Coke	(0.687)	27.85	**(19.1)**
	Other Oil for petrochemical feedstocks	0.398	19.95	**7.9**
	Special Napthas	(0.028)	19.86	**(0.6)**
	Lubricants	(0.045)	20.24	**(0.9)**
	Waxes	(0.003)	19.81	**(0.1)**
	Asphalt/Road Oil	0.049	20.62	**1.0**
	Still Gas	0.000	17.51	**0.0**
	Misc. Products	0.112	19.81	**2.2**
Total				**1,573.9**

Data Sources: Coal and Lignite - *Revised 1996 IPCC Guidelines Reference Manual*, Table 1-1; Coke - EIA *Monthly Energy Review*, November 1998 Table C1; Unspecified Solid Fuels - EIA *Monthly Energy Review*, November 1998 Table C1 (U.S. Average); Natural Gas and Liquid Fuels - EIA *Emissions of Greenhouse Gases in the United States 1997.*
Note: Totals may not sum due to independent rounding.

Table O-5: 1997 Non-Energy Carbon Stored in Products

Fuel Type	Consumption for Non-Energy Use (TBtu)	Carbon Coefficients (MMTCE/QBtu)	Carbon Content (MMTCE)	Fraction Sequestered	Carbon Sequestered (MMTCE)
Coal	27.7	25.55	0.7	0.75	**0.5**
Natural Gas	391.4	14.47	5.7	1.00	**5.7**
Asphalt & Road Oil	1223.6	20.62	25.2	1.00	**25.2**
LPG	1651.3	16.86	27.8	0.80	**22.3**
Lubricants	354.4	20.24	7.2	0.50	**3.6**
Pentanes Plus	295.4	18.24	5.4	0.80	**4.3**
Petrochemical Feedstocks	[1]	[1]	[1]	[1]	**15.9**
Petroleum Coke	179.0	27.85	5.0	0.50	**2.5**
Special Naptha	72.3	19.86	1.4	0	**0.0**
Waxes/Misc.	[1]	[1]	[1]	[1]	**3.4**
Misc. U.S. Territories Petroleum	[1]	[1]	[1]	[1]	**0.2**
Total					**83.6**

[1] Values for Misc. U.S. Territories Petroleum, Petrochemical Feedstocks and Waxes/Misc. are not shown because these categories are aggregates of numerous smaller components.
Note: Totals may not sum due to independent rounding.

Table O-6: Reference Approach CO_2 Emissions from Fossil Fuel Consumption (MMTCE unless otherwise noted)

Fuel Category	Potential Carbon Emissions	Carbon Sequestered	Net Carbon Emissions	Fraction Oxidized (percent)	CO_2 Emissions (MMTCE)	CO_2 Emissions (Tg)
Coal	548.0	0.5	547.5	99.0%	**542.0**	**1,987.4**
Petroleum	699.2	77.4	621.7	99.0%	**615.5**	**2,256.9**
Natural Gas	326.7	5.7	321.0	99.5%	**319.4**	**1,171.1**
Total	1,573.9	83.6	1,490.2	-	**1,476.9**	**5,415.4**

Note: Totals may not sum due to independent rounding.

Table O-7: 1997 Energy Consumption in the United States: Sectoral vs. Reference Approaches (TBtu)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	20,931.8	22,575.3	35,632.8	79,140.0
Reference (Apparent)[a]	21,011.1	22,575.7	35,272.4	78,859.3
Difference	**0.4%**	**0.0%**	**-1.0%**	**-0.4%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-8: 1997 CO_2 Emissions from Fossil Fuel Combustion by Estimating Approach (MMTCE)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	533.3	319.4	613.3	1,465.9
Reference[a]	542.0	319.4	615.5	1,476.9
Difference	**1.6%**	**0.0%**	**0.4%**	**0.8%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-9: 1996 Energy Consumption in the United States: Sectoral vs. Reference Approaches (TBtu)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	20,459	22,552	35,170	78,181
Reference (Apparent)[a]	20,334	22,547	34,642	77,523
Difference	**-0.6%**	**0.0%**	**-1.5%**	**-0.8%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Table O-10: 1996 CO_2 Emissions from Fossil Fuel Combustion by Estimating Approach (MMTCE)

Approach	Coal	Natural Gas	Petroleum	Total
Sectoral[a]	521.1	319.3	607.2	1,447.7
Reference[a]	524.7	319.3	605.6	1,449.5
Difference	**0.7%**	**0.0%**	**-0.3%**	**0.1%**

[a] Includes U.S. territories
Note: Totals may not sum due to independent rounding.

Annex P
Sources of Greenhouse Gas Emissions Excluded

Although this report is intended to be a comprehensive assessment of anthropogenic[22] sources and sinks of greenhouse gas emissions for the United States, certain sources have been identified yet excluded from the estimates presented for various reasons. Before discussing these sources, however, it is important to note that processes or activities that are not *anthropogenic in origin* or do not result in a *net source or sink* of greenhouse gas emissions are intentionally excluded from a national inventory of anthropogenic greenhouse gas emissions. In general, processes or activities that are not anthropogenic are considered natural (i.e., not directly influenced by human activity) in origin and, as an example, would include the following:

- Volcanic eruptions
- CO_2 exchange (i.e., uptake or release) by oceans
- Natural forest fires[23]
- CH_4 emissions from wetlands not affected by human induced land-use changes

Some processes or activities may be anthropogenic in origin but do not result in net emissions of greenhouse gases, such as the respiration of CO_2 by people or domesticated animals. Given a source category that is both anthropogenic and results in net greenhouse gas emissions, reasons for excluding a source related to an anthropogenic activity include one or more of the following:

- There is insufficient scientific understanding to develop a reliable method for estimating emissions at a national level.
- Although an estimating method has been developed, data were not adequately available to calculate emissions.
- Emissions were implicitly accounted for within another source category (e.g., CO_2 from Fossil Fuel Combustion).

It is also important to note that the United States believes the exclusion of the sources discussed below introduces only a minor bias in its overall estimate of U.S. greenhouse gas emissions.

CH_4, N_2O, and Criteria Pollutant Emissions from the Combustion of Jet Fuel

The combustion of jet fuel by aircraft results in emissions of CH_4, N_2O, CO, NO_x, and NMVOCs. The emissions per mass of fuel combusted during landing/take-off (LTO) operations differ from those during aircraft cruising. Accurate estimation of these emissions requires a detailed accounting of LTO cycles and fuel consumption during cruising by aircraft model (e.g., Boeing 747-400). Sufficient data for separately calculating near ground-level emissions during landing and take-off and cruise altitude emissions by aircraft model were not available for this report. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, pp. 1.93 - 1.96)

[22] The term "anthropogenic", in this context, refers to greenhouse gas emissions and removals that are a direct result of human activities or are the result of natural processes that have been affected by human activities (IPCC/UNEP/OECD/IEA 1997).

[23] In some cases forest fires that are started either intentionally or unintentionally are viewed as mimicking natural burning processes which have been suppressed by other human forest management activities. The United States does not consider forest fires within its national boundaries to be a net source of greenhouse emissions.

Emissions from Bunker Fuels and Fossil Fuels Combusted Abroad by the U.S. Military

Emissions from fossil fuels combusted in military vehicles (i.e., ships, aircraft, and ground vehicles) may or may not be included in U.S. energy statistics. Domestic fuel sales to the military are captured in U.S. energy statistics; however, fuels purchased abroad for base operations and refueling of vehicles are not. It is not clear to what degree fuels purchased domestically are exported by the military to bases abroad.

Fuels combusted by military ships and aircraft while engaged in international transport or operations in international waters or airspace (i.e., flying or cruising in international airspace or waters) that is purchased domestically is included in U.S. energy statistics. Therefore, the United States may under report international bunker fuel emissions, and most likely over reports CO_2 emissions from transportation-related fossil fuel combustion by a similar amount. At this time, fuel consumption statistics from the Department of Defense are not adequately detailed to correct for this bias.[24]

CO_2 from Burning in Coal Deposits and Waste Piles

Coal is periodically burned in deposits and waste piles. It has been estimated that the burning of coal in deposits and waste piles would represent less than 1.3 percent of total U.S. coal consumption (averaged over ten-years). Because there is currently no known source of data on the quantity of coal burned in waste piles and there is uncertainty as to the fraction of coal oxidized during such burnings, these CO_2 emissions are not currently estimated. Further research would be required to develop accurate emission factors and activity data for these emissions to be estimated. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 1.112 - 1.113)

Fossil CO_2 from Petroleum and Natural Gas Wells, CO_2 Separated from Natural Gas, and CO_2 from Enhanced Oil Recovery (EOR)

Petroleum and natural gas well drilling, petroleum and natural gas production, and natural gas processing—including removal of CO_2—may result in emissions of CO_2 that was at one time stored in underground formations.

Carbon dioxide and other gases are naturally present in raw natural gas, in proportions that vary depending on the geochemical circumstances that caused the formation of the gas. After the heavier gases are removed, small amounts of carbon dioxide may be allowed to remain in the natural gas. If the amount of CO_2 sufficiently lowers the heating value of the natural gas, it is typically extracted by amine scrubbing and, in most cases, emitted into the atmosphere. These emissions can be estimated by calculating the difference between the average carbon dioxide content of raw natural gas and the carbon dioxide content of pipeline gas. The Energy Information Administration (EIA) estimates that annual CO_2 emissions from scrubbing are about 4 million metric tons of carbon. Because of imprecision in the reporting of U.S. natural gas production and processing, emissions estimates from energy production sources may be double-counted or under-reported, and thus are uncertain.

Carbon dioxide is also injected into underground deposits to increase crude oil reservoir pressure in a field technique known as enhanced oil recovery (EOR). It is thought that much of the injected CO_2 may be effectively and permanently sequestered, but the fraction of injected CO_2 that is re-released remains uncertain. The fraction re-released varies from well to well depending upon the field geology and the gas capture/re-injection technology employed at the wellhead. Over time, carbon dioxide may also seep into the producing well and mix with the oil and natural gas present there. If the gas portion of this mixture has a sufficiently high energy content, it may be collected and sent to a natural gas plant; if not, it may be vented or flared. The EIA estimates that the amount of CO_2 used for EOR is on the order of 12 million metric tons, of which emissions would be some fraction yet to be defined. This figure is based on the difference between U.S. Department of Commerce sales figures for industrial CO_2 (17 million metric tons) minus the 5 million metric tons reported by the Freedonia Group that is used for purposes other than EOR. Further research

[24] See the Defense Energy Support Center (formerly the Defense Fuel Supply Center), *Fact Book 1997*. [http://www.desc.dla.mil/main/pulicati.htm]

into EOR is required before the resulting CO_2 emissions can be adequately quantified. (See the discussion of the Carbon Dioxide Consumption source category in the Industrial Processes chapter).

Carbon Sequestration in Underground Injection Wells

Organic hazardous wastes are injected into underground wells. Depending on the source of these organic substances (e.g., derived from fossil fuels) the carbon in them may or may not be included in U.S. CO_2 emission estimates. Sequestration of carbon containing substances in underground injection wells may be an unidentified sink. Further research is required if this potential sink is to be quantified.

CH_4 from Abandoned Coal Mines

Abandoned coal mines are a source of CH_4 emissions. In general, many of the same factors that affect emissions from operating coal mines will affect emissions from abandoned mines such as the permeability and gassiness of the coal, the mine's depth, geologic characteristics, and whether it has been flooded. A few gas developers have recovered methane from abandoned mine workings; therefore, emissions from this source may be significant. Further research and methodological development is needed if these emissions are to be estimated.

CO_2 from "Unaccounted for" Natural Gas

There is a discrepancy between the amount of natural gas sold by producers and that reported as purchased by consumers. This discrepancy, known as "unaccounted for" or unmetered natural gas, was assumed to be the sum of leakage, measurement errors, data collection problems, undetected non-reporting, undetected over reporting, and undetected under reporting. Historically, the amount of gas sold by producers has always exceeded that reportedly purchased by consumers; therefore, some portion of unaccounted for natural gas was assumed to be a source of CO_2 emissions. (It was assumed that consumers were underreporting their usage of natural gas.) In DOE/EIA's energy statistics for 1996, however, reported consumption of natural gas exceeded the amount sold by producers. Therefore, the historical explanation given for this discrepancy has lost credibility and unaccounted for natural gas is no longer used to calculate CO_2 emissions.

CO_2 from Shale Oil Production

Oil shale is shale saturated with kerogen.[25] It can be thought of as the geological predecessor to crude oil. Carbon dioxide is released as a by-product of the process of producing petroleum products from shale oil. As of now, it is not cost-effective to mine and process shale oil into usable petroleum products. The only identified large-scale oil shale processing facility in the U.S. was operated by Unocal during the years 1985 to 1990. There have been no known emissions from shale oil processing in the United States since 1990 when the Unocal facility closed.

CH_4 from the Production of Carbides other than Silicon Carbide

Methane may be emitted from the production of carbides because the petroleum coke used in the process contains volatile organic compounds which form methane during thermal decomposition. Methane emissions from the production of silicon carbide were estimated and accounted for, but emissions from the production of calcium carbide and other carbides were not. Further research is needed to estimate CH_4 emissions from the production of calcium carbide and other carbides other than silicon carbide. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, pp. 2.20 - 2.21)

CO_2 from Calcium Carbide and Silicon Carbide Production

Carbon dioxide is formed by the oxidation of petroleum coke in the production of both calcium carbide and silicon carbide. These CO_2 emissions are implicitly accounted for with emissions from the combustion of petroleum

[25] Kerogen is fossilized insoluble organic material found in sedimentary rocks, usually shales, which can be converted to petroleum products by distillation.

coke in the Energy chapter. There is currently not sufficient data on coke consumption to estimate emissions from these sources explicitly. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, pp. 2.20 - 2.21)

CO_2 from Graphite Consumption in Ferroalloy and Steel Production

The CO_2 emissions from the three reducing agents used in ferroalloy and steel production—coke, wood (or biomass), and graphite—are accounted for as follows:

- Emissions resulting from the use of coke are accounted for in the Energy chapter under fossil fuel combustion.
- Estimating emissions from the use of wood or other biomass materials is unnecessary because these emissions should be accounted for in Land-Use Change and Forestry chapter if the biomass is harvested on an unsustainable basis.
- The CO_2 emissions from the use of graphite, which is produced from petroleum by-products, may be accounted for in the Energy chapter (further analysis is required to determine if these emissions are being properly estimated). The CO_2 emissions from the use of natural graphite, however, have not been accounted for in the estimate.

Emissions from graphite electrode consumption—versus its use as a reducing agent—in ferroalloy and steel production may at present only be accounted for in part under fossil fuel combustion if the graphite used was derived from a fossil fuel substrate (versus natural graphite ore). Further research into the source and total consumption of graphite for these purposes is required to explicitly estimate emissions. (see Iron and Steel Production and Ferroalloy Production in the Industrial Processes chapter)

N_2O from Caprolactam Production

Caprolactam is a widely used chemical intermediate, primarily to produce nylon-6. All processes for producing caprolactam involve the catalytic oxidation of ammonia, with N_2O being produced as a by-product. Caprolactam production could be a significant source of N_2O—it has been identified as such in the Netherlands. More research is required to determine this source's significance because there is currently insufficient information available on caprolactam production to estimate emissions in the United States. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, pp. 2.22 - 2.23)

N_2O from Cracking of Certain Oil Fractions

In order to improve the gasoline yield in crude oil refining, certain oil fractions are processed in a catcracker. Because crude oil contains some nitrogen, N_2O emissions may result from this cracking process. There is currently insufficient data to develop a methodology for estimating these emissions. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 2.23)

CH_4 from Coke Production

Coke production may result in CH_4 emissions. Detailed coke production statistics were not available for the purposes of estimating CH_4 emissions from this minor source. (see Petrochemical Production in the Industrial Processes chapter and the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 2.23)

CO_2 from Metal Production

Coke is used as a reducing agent in the production of some metals from their ores, including magnesium, chromium, lead, nickel, silicon, tin, titanium, and zinc. Carbon dioxide may be emitted during the metal's production from the oxidization of this coke and, in some cases, from the carbonate ores themselves (e.g., some magnesium ores contain carbonate). The CO_2 emissions from coke oxidation are accounted for in the Energy chapter under Fossil Fuel Combustion. The CO_2 emissions from the carbonate ores are not presently accounted for, but their quantities are thought to be minor. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 2.37 - 2.38)

N_2O from Acrylonitrile Production

Nitrous oxide may be emitted during acrylonitrile production. No methodology was available for estimating these emissions, and therefore further research is needed if these emissions are to be included. (see *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual*, p. 2.22)

SF_6 from Aluminum Fluxing and Degassing

Occasionally, sulfur hexafluoride (SF_6) is used by the aluminum industry as a fluxing and degassing agent in experimental and specialized casting operations. In these cases it is normally mixed with argon, nitrogen, and/or chlorine and blown through molten aluminum; however, this practice is not used by primary aluminum production firms in the United States and is not believed to be extensively used by secondary casting firms. Where it does occur, the concentration of SF_6 in the mixture is small and a portion of the SF_6 is decomposed in the process (Waite and Bernard 1990, Corns 1990). It has been estimated that 230 Mg of SF_6 were used by the aluminum industry in the United States and Canada (Maiss and Brenninkmeijer 1998); however, this estimate is highly uncertain.

Miscellaneous SF_6 Uses

Sulfur hexafluoride may be used in gas-filled athletic shoes, in foam insulation, for dry etching, in laser systems, as an atmospheric tracer gas, for indoor air quality testing, for laboratory hood testing, for chromatography, in tandem accelerators, in sound-insulating windows, in tennis balls, in loudspeakers, in shock absorbers, and for certain biomedical applications. Data need to be gathered and methodologies developed if these emissions are to be estimated. A preliminary global assessment of aggregate emissions from these applications can be found in Maiss, M. and C.A.M. Brenninkmeijer (1998).

CO_2 from Solvent Incineration

CO_2 may be released during the incineration of solvents. Although emissions from this source are believed to be minor, data need to be gathered and methodologies developed if these emissions are to be estimated.

CO_2 from Non-Forest Soils

Non-forest soils emit CO_2 from decaying organic matter and carbonate minerals—the latter may be naturally present or mined and later applied to soils as a means to adjust their acidity. Soil conditions, climate, and land-use practices interact to affect the CO_2 emission rates from non-forest soils. The U.S. Forest Service has developed a model to estimate CO_2 emissions from forest soils, but no such model has been adequately developed for non-forest soils. Further research and methodological development is needed if these emissions are to be accurately estimated. (see Changes in Non-Forest Carbon Stocks in the Land-Use Change and Forestry chapter)

CH_4 from Land-Use Changes Including Wetlands Creation or Destruction

Wetlands are a known source of CH_4 emissions. When wetlands are destroyed, CH_4 emissions may be reduced. Conversely, when wetlands are created (e.g., during the construction of hydroelectric plants), CH_4 emissions may increase. Grasslands and forest lands may also be weak sinks for CH_4 due to the presence of methanotrophic bacteria that use CH_4 as an energy source (i.e., they oxidize CH_4 to CO_2). Currently, an adequate scientific basis for estimating these emissions and sinks does not exist, and therefore further research and methodological development is required.

CH_4 from Septic Tanks and Drainfields

Methane is produced during the biodegradation of organics in septic tanks if other suitable electron-acceptors (i.e., oxygen, nitrate, or sulfate) besides CO_2 are unavailable. Such conditions are called methanogenic. There were insufficient data and methodological developments available to estimate emissions from this source.

N_2O from Wastewater Treatment

As a result of nitrification and denitrification processes, N_2O may be produced and emitted from both domestic and industrial wastewater treatment plants. Nitrogen-containing compounds are found in wastewater due to the presence of both human excrement and other nitrogen-containing constituents (e.g. garbage, industrial wastes, dead animals, etc.). The portion of emitted N_2O which originates from human excrement is currently estimated under the Human Sewage source category—based upon average dietary assumptions. The portion of emitted N_2O which originates from other nitrogen-containing constituents is not currently estimated. Further research and methodological development is needed if these emissions are to be accurately estimated.

CH_4 from Industrial Wastewater

Methane may be produced during the biodegradation of organics in wastewater treatment if other suitable electron-acceptors (i.e. oxygen, nitrate, or sulfate) besides CO_2 are unavailable. Such conditions are called methanogenic. Methane produced from domestic wastewater treatment plants is accounted for in the Waste chapter. These emissions are estimated by assuming an average 5-day biological oxygen demand (BOD_5) per capita contribution in conjunction with the approximation that 15 percent of wastewater's BOD_5 is removed under methanogenic conditions. This method itself needs refinement. It is not clear if industrial wastewater sent to domestic wastewater treatment plants, which may contain biodegradable material, are accounted for in the average BOD_5 per capita method when this wastewater is sent to domestic wastewater treatment plants. Additionally, CH_4 emissions from methanogenic processes at industrial wastewater treatment plants are not currently estimated. Further research and methodological development is needed if these emissions are to be accurately estimated. (see Wastewater Treatment in the Waste chapter)

Annex Q
Constants, Units, and Conversions

Metric Prefixes

Although most activity data for the U.S. is gathered in customary U.S. units, these units are converted into metric units per international reporting guidelines. The following table provides a guide for determining the magnitude of metric units.

Table Q-1: Guide to Metric Unit Prefixes

Prefix/Symbol	Factor
atto (a)	10^{-18}
femto (f)	10^{-15}
pico (p)	10^{-12}
nano (n)	10^{-9}
micro (μ)	10^{-6}
milli (m)	10^{-3}
centi (c)	10^{-2}
deci (d)	10^{-1}
deca (da)	10
hecto (h)	10^{2}
kilo (k)	10^{3}
mega (M)	10^{6}
giga (G)	10^{9}
tera (T)	10^{12}
peta (P)	10^{15}
exa (E)	10^{18}

Unit Conversions

1 kilogram	= 2.205 pounds			
1 pound	= 0.454 kilograms			
1 short ton	= 2,000 pounds	= 0.9072 metric tons		
1 metric ton	= 1,000 kilograms	= 1.1023 short tons		

1 cubic meter = 35.315 cubic feet
1 cubic foot = 0.02832 cubic meters
1 U.S. gallon = 3.785412 liters
1 barrel (bbl) = 0.159 cubic meters
1 barrel (bbl) = 42 U.S. gallons
1 liter = 0.1 cubic meters

1 foot = 0.3048 meters
1 meter = 3.28 feet
1 mile = 1.609 kilometers
1 kilometer = 0.622 miles

1 acre = 43,560 square feet = 0.4047 hectares = 4,047 square meters
1 square mile = 2.589988 square kilometers

To convert degrees Fahrenheit to degrees Celsius, subtract 32 and multiply by 5/9
To convert degrees Celsius to Kelvin, add 273.15 to the number of Celsius degrees

Density Conversions[26]

Methane	1 cubic meter	=	0.67606 kilograms
Carbon dioxide	1 cubic meter	=	1.85387 kilograms

Natural gas liquids	1 metric ton	=	11.6 barrels	=	1,844.2 liters
Unfinished oils	1 metric ton	=	7.46 barrels	=	1,186.04 liters
Alcohol	1 metric ton	=	7.94 barrels	=	1,262.36 liters
Liquefied petroleum gas	1 metric ton	=	11.6 barrels	=	1,844.2 liters
Aviation gasoline	1 metric ton	=	8.9 barrels	=	1,415.0 liters
Naphtha jet fuel	1 metric ton	=	8.27 barrels	=	1,314.82 liters
Kerosene jet fuel	1 metric ton	=	7.93 barrels	=	1,260.72 liters
Motor gasoline	1 metric ton	=	8.53 barrels	=	1,356.16 liters
Kerosene	1 metric ton	=	7.73 barrels	=	1,228.97 liters
Naphtha	1 metric ton	=	8.22 barrels	=	1,306.87 liters
Distillate	1 metric ton	=	7.46 barrels	=	1,186.04 liters
Residual oil	1 metric ton	=	6.66 barrels	=	1,058.85 liters
Lubricants	1 metric ton	=	7.06 barrels	=	1,122.45 liters
Bitumen	1 metric ton	=	6.06 barrels	=	963.46 liters
Waxes	1 metric ton	=	7.87 barrels	=	1,251.23 liters
Petroleum coke	1 metric ton	=	5.51 barrels	=	876.02 liters
Petrochemical feedstocks	1 metric ton	=	7.46 barrels	=	1,186.04 liters
Special naphtha	1 metric ton	=	8.53 barrels	=	1,356.16 liters
Miscellaneous products	1 metric ton	=	8.00 barrels	=	1,271.90 liters

Energy Conversions

Converting Various Energy Units to Joules

The common energy unit used in international reports of greenhouse gas emissions is the joule. A joule is the energy required to push with a force of one Newton for one meter. A terajoule (TJ) is one trillion (10^{12}) joules. A British thermal unit (Btu, the customary U.S. energy unit) is the quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at or near 39.2 Fahrenheit.

1 TJ = 2.388×10^{11} calories
23.88 metric tons of crude oil equivalent
947.8 million Btus
277,800 kilowatt-hours

Converting Various Physical Units to Energy Units

Data on the production and consumption of fuels are first gathered in physical units. These units must be converted to their energy equivalents. The values in the following table of conversion factors can be used as default factors, if local data are not available. See Appendix A of EIA's *Annual Energy Review 1997* (EIA 1998) for more detailed information on the energy content of various fuels.

[26] Reference: EIA (1998a)

Table Q-2: Conversion Factors to Energy Units (heat equivalents)

Fuel Type (Units)	Factor
Solid Fuels (Million Btu/Short ton)	
Anthracite coal	22.573
Bituminous coal	23.89
Sub-bituminous coal	17.14
Lignite	12.866
Coke	24.8
Natural Gas (Btu/Cubic foot)	1,027
Liquid Fuels (Million Btu/Barrel)	
Crude oil	5.800
Natural gas liquids and LRGs	3.777
Other liquids	5.825
Motor gasoline	5.253
Aviation gasoline	5.048
Kerosene	5.670
Jet fuel, kerosene-type	5.670
Distillate fuel	5.825
Residual oil	6.287
Naphtha for petrochemicals	5.248
Petroleum coke	6.024
Other oil for petrochemicals	5.825
Special naphthas	5.248
Lubricants	6.065
Waxes	5.537
Asphalt	6.636
Still gas	6.000
Misc. products	5.796

Note: For petroleum and natural gas, *Annual Energy Review 1997* (EIA 1998b). For coal ranks, *State Energy Data Report 1992* (EIA 1993). All values are given in higher heating values (gross calorific values).

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Annex R
Abbreviations

AFEAS	Alternative Fluorocarbon Environmental Acceptability Study
AAPFCO	American Association of Plant Food Control Officials
ASAE	American Society of Agricultural Engineers
BEA	Bureau of Economic Analysis, U.S. Department of Commerce
BOD_5	Biochemical oxygen demand over a 5-day period
BTS	Bureau of Transportation Statistics, U.S. Department of Transportation
Btu	British thermal unit
CAAA	Clean Air Act Amendments of 1990
C&EN	Chemical and Engineering News
CFC	Chlorofluorocarbon
CMA	Chemical Manufacturers Association
CMOP	Coalbed Methane Outreach Program
CVD	Chemical vapor deposition
DIC	Dissolved inorganic carbon
DOC	U.S. Department of Commerce
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EIA	Energy Information Administration, U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FAA	Federal Aviation Administration
FAO	Food and Agricultural Organization
FCCC	Framework Convention on Climate Change
FHWA	Federal Highway Administration
GAA	Governmental Advisory Associates
GHG	Greenhouse gas
GRI	Gas Research Institute
GSAM	Gas Systems Analysis Model
GWP	Global warming potential
HBFC	Hydrobromofluorocarbon
HCFC	Hydrochlorofluorocarbon
HDGV	Heavy duty gas vehicle
HDDV	Heavy duty diesel vehicle
HFC	Hydrofluorocarbon
HFE	Hydrofluoroethers
ICAO	International Civil Aviation Organization
IEA	International Energy Association
ILENR	Illinois Department of Energy and Natural Resources
IMO	International Maritime Organization
IPAA	Independent Petroleum Association of America
IPCC	Intergovernmental Panel on Climate Change
LDDT	Light duty diesel truck
LDDV	Light duty diesel vehicle
LDGV	Light duty gas vehicle
LDGT	Light duty gas truck
LFG	Landfill gas
LPG	Liquefied petroleum gas(es)
MC	Motorcycle
MMTCE	Million metric tons of carbon equivalent
MSW	Municipal solid waste
NIAR	Norwegian Institute for Air Research
NMVOCs	Nonmethane volatile organic compounds

NO_x	Nitrogen Oxides
NVFEL	National Vehicle Fuel Emissions Laboratory
OAQPS	EPA Office of Air Quality Planning and Standards
ODS	Ozone depleting substances
OECD	Organization of Economic Co-operation and Development
OMS	EPA Office of Mobile Sources
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OTA	Office of Technology Assessment
PFC	Perfluorocarbon
PFPE	Perfluoropolyether
ppmv	Parts per million(10^6) by volume
ppbv	Parts per billion (10^9) by volume
pptv	Parts per trillion (10^{12}) by volume
SAE	Society of Automotive Engineers
SNG	Synthetic natural gas
TBtu	Trillion Btu
TJ	Terajoule
TSDF	Hazardous waste treatment, storage, and disposal facility
TVA	Tennessee Valley Authority
U.S.	United States
USDA	United States Department of Agriculture
USFS	United States Forest Service
USGS	United States Geological Survey
UNEP	United Nations Environmental Programme
UNFCCC	United Nations Framework Convention on Climate Change
VAIP	EPA's Voluntary Aluminum Industrial Partnership
VMT	Vehicle miles traveled
WMO	World Meteorological Organization

Annex S

Chemical Symbols

Table S-1: Guide to Chemical Symbols

Symbol	Name
Al	Aluminum
Al_2O_3	Aluminum Oxide
Br	Bromine
C	Carbon
CH_4	Methane
C_2H_6	Ethane
C_3H_8	Propane
CF_4	Perfluoromethane
C_2F_6	Perfluoroethane, hexafluoroethane
C_3F_8	Perfluoropropane
$c\text{-}C_4F_8$	Perfluorocyclobutane
C_5F_{12}	Perfluoropentane
C_6F_{14}	Perfluorohexane
CF_3I	Trifluoroiodomethane
$CFCl_3$	Trichlorofluoromethane (CFC-11)
CF_2Cl_2	Dichlorodifluoromethane (CFC-12)
CF_3Cl	Chlorotrifluoromethane (CFC-13)
$C_2F_3Cl_3$	Trichlorotrifluoroethane (CFC-113)*
CCl_3CF_3	CFC-113a*
$C_2F_4Cl_2$	Dichlorotetrafluoroethane (CFC-114)
C_2F_5Cl	Chloropentafluoroethane (CFC-115)
CHF_2Cl	Chlorodifluoromethane (HCFC-22)
$C_2F_3HCl_2$	HCFC-123
C_2F_4HCl	HCFC-124
C_2FH3Cl_2	HCFC-141b
$C_2H_3F_2Cl$	HCFC-142b
$C_3F_5HCl_2$	HCFC-225ca/cb
CCl_4	Carbon tetrachloride
$CHClCCl_2$	Trichloroethylene
CCl_2CCl_2	Perchloroethylene, tetrachloroethene
CH_3Cl	Methylchloride
CH_3CCl_3	Methylchloroform
CH_2Cl_2	Methylenechloride
$CHCl_3$	Chloroform, trichloromethane
CHF_3	HFC-23
CH_2F_2	HFC-32
CH_3F	HFC-41
C_2HF_5	HFC-125
$C_2H_2F_4$	HFC-134
CH_2FCF_3	HFC-134a
$C_2H_3F_3$	HFC-143*
$C_2H_3F_3$	HFC-143a*
$C_2H_4F_2$	HFC-152a
C_3HF_7	HFC-227ea
$C_3H_2F_6$	HFC-236fa
$C_3H_3F_5$	HFC-245ca
$C_5H_2F_{10}$	HFC-43-10mee
CH_2Br_2	Dibromomethane
CH_2BrCl	Dibromochloromethane
$CHBr_3$	Tribromomethane

CH_3Br	Methylbromide
CF_2BrCl	Bromodichloromethane (Halon 1211)
$CF_3Br(CBrF_3)$	Bromotrifluoromethane (Halon 1301)
CO	Carbon monoxide
CO_2	Carbon dioxide
$CaCO_3$	Calcium carbonate, Limestone
$CaMg(CO_3)_2$	Dolomite
CaO	Calcium oxide, Lime
Cl	atomic Chlorine
F	Fluorine
Fe	Iron
Fe_2O_3	Ferric oxide
FeSi	Ferrosilicon
H, H_2	atomic Hydrogen, molecular Hydrogen
H_2O	Water
H_2O_2	Hydrogen peroxide
OH	Hydroxyl
N, N_2	atomic Nitrogen, molecular Nitrogen
NH_3	Ammonia
NH_4^+	Ammonium ion
HNO_3	Nitric Acid
NF_3	Nitrogen trifluoride
N_2O	Nitrous oxide
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_3	Nitrate radical
Na	Sodium
Na_2CO_3	Sodium carbonate, soda ash
Na_3AlF_6	Synthetic cryolite
O, O_2	atomic Oxygen, molecular Oxygen
O_3	Ozone
S	atomic Sulfur
H_2SO_4	Sulfuric acid
SF_6	Sulfur hexafluoride
SO_2	Sulfur dioxide
Si	Silicon
SiC	Silicon carbide
SiO_2	Quartz

* Distinct isomers.

Annex T
Glossary

Abiotic. [7] Nonliving. Compare *biotic*.

Absorption of radiation.[1] The uptake of radiation by a solid body, liquid or gas. The absorbed energy may be transferred or re-emitted.

Acid deposition. [6] A complex chemical and atmospheric process whereby recombined emissions of sulfur and nitrogen compounds are redeposited on earth in wet or dry form. See *acid rain*.

Acid rain. [6] Rainwater that has an acidity content greater than the postulated natural pH of about 5.6. It is formed when sulfur dioxides and nitrogen oxides, as gases or fine particles in the atmosphere, combine with water vapor and precipitate as sulfuric acid or nitric acid in rain, snow, or fog. The dry forms are acidic gases or particulates. See *acid deposition*.

Acid solution. [7] Any water solution that has more hydrogen ions (H+) than hydroxide ions (OH-); any water solution with a pH less than 7. See *basic solution, neutral solution*.

Acidic. [7] See *acid solution*.

Adiabatic process. [9] A thermodynamic change of state of a system such that no heat or mass is transferred across the boundaries of the system. In an adiabatic process, expansion always results in cooling, and compression in warming.

Aerosol. [1&9] Particulate matter, solid or liquid, larger than a molecule but small enough to remain suspended in the atmosphere. Natural sources include salt particles from sea spray, dust and clay particles as a result of weathering of rocks, both of which are carried upward by the wind. Aerosols can also originate as a result of human activities and are often considered pollutants. Aerosols are important in the atmosphere as nuclei for the condensation of water droplets and ice crystals, as participants in various chemical cycles, and as absorbers and scatters of solar radiation, thereby influencing the radiation budget of the Earth's climate system. See *climate, particulate matter*.

Afforestation. [2] Planting of new forests on lands that have not been recently forested.

Air carrier [8] An operator (e.g., airline) in the commercial system of air transportation consisting of aircraft that hold certificates of, Public Convenience and Necessity, issued by the Department of Transportation, to conduct scheduled or non-scheduled flights within the country or abroad.

Air pollutant. See *air pollution*.

Air pollution. [7] One or more chemicals or substances in high enough concentrations in the air to harm humans, other animals, vegetation, or materials. Such chemicals or physical conditions (such as excess heat or noise) are called air pollutants.

Albedo. [9] The fraction of the total solar radiation incident on a body that is reflected by it.

Alkalinity. [6] Having the properties of a base with a pH of more than 7. A common alkaline is baking soda.

Alternative energy. [6] Energy derived from nontraditional sources (e.g., compressed natural gas, solar, hydroelectric, wind).

Anaerobic. [6] A life or process that occurs in, or is not destroyed by, the absence of oxygen.

Anaerobic decomposition. [2] The breakdown of molecules into simpler molecules or atoms by microorganisms that can survive in the partial or complete absence of oxygen.

Anaerobic lagoon. [2] A liquid-based manure management system, characterized by waste residing in water to a depth of at least six feet for a period ranging between 30 and 200 days. Bacteria produce methane in the absence of oxygen while breaking down waste.

Anaerobic organism. [7] Organism that does not need oxygen to stay alive. See *aerobic organism*.

Antarctic "Ozone Hole." [6] Refers to the seasonal depletion of stratospheric ozone in a large area over Antarctica. See *ozone layer*.

Anthracite.[2] A hard, black, lustrous coal containing a high percentage of fixed carbon and a low percentage of volatile matter. Often referred to as hard coal.

Anthropogenic.[2] Human made. In the context of greenhouse gases, emissions that are produced as the result of human activities.

Arable land.[7] Land that can be cultivated to grow crops.

Aromatic.[6] Applied to a group of hydrocarbons and their derivatives characterized by the presence of the benzene ring.

Ash.[6] The mineral content of a product remaining after complete combustion.

Asphalt.[2] A dark-brown-to-black cement-like material containing bitumen as the predominant constituent. It is obtained by petroleum processing. The definition includes crude asphalt as well as the following finished products: cements, fluxes, the asphalt content of emulsions (exclusive of water), and petroleum distillates blended with asphalt to make cutback asphalt.

Atmosphere.[1] The mixture of gases surrounding the Earth. The Earth's atmosphere consists of about 79.1 percent nitrogen (by volume), 20.9 percent oxygen, 0.036 percent carbon dioxide and trace amounts of other gases. The atmosphere can be divided into a number of layers according to its mixing or chemical characteristics, generally determined by its thermal properties (temperature). The layer nearest the Earth is the *troposphere*, which reaches up to an altitude of about 8 kilometers (about 5 miles) in the polar regions and up to 17 kilometers (nearly 11 miles) above the equator. The *stratosphere*, which reaches to an altitude of about 50 kilometers (31miles) lies atop the troposphere. The *mesosphere*, which extends from 80 to 90 kilometers atop the stratosphere, and finally, the *thermosphere*, or *ionosphere*, gradually diminishes and forms a fuzzy border with outer space. There is relatively little mixing of gases between layers.

Atmospheric lifetime. See *lifetime*.

Atomic weight.[6] The average weight (or mass) of all the isotopes of an element, as determined from the proportions in which they are present in a given element, compared with the mass of the 12 isotope of carbon (taken as precisely 12.000), that is the official international standard; measured in daltons.

Atoms.[7] Minute particles that are the basic building blocks of all chemical elements and thus all matter.

Aviation Gasoline.[8] All special grades of gasoline for use in aviation reciprocating engines, as given in the American Society for Testing and Materials (ASTM) specification D 910. Includes all refinery products within the gasoline range that are to be marketed straight or in blends as aviation gasoline without further processing (any refinery operation except mechanical blending). Also included are finished components in the gasoline range, which will be used for blending or compounding into aviation gasoline.

Bacteria.[7] One-celled organisms. Many act as decomposers that break down dead organic matter into substances that dissolve in water and are used as nutrients by plants.

Barrel (bbl).[6] A liquid-volume measure equal to 42 United States gallons at 60 degrees Fahrenheit; used in expressing quantities of petroleum-based products.

Basic solution.[7] Water solution with more hydroxide ions (OH-) than hydrogen ions (H+); water solutions with pH greater than 7. See *acid solution, alkalinity, acid*.

Biodegradable.[7] Material that can be broken down into simpler substances (elements and compounds) by bacteria or other decomposers. Paper and most organic wastes such as animal manure are biodegradable. See *nonbiodegradable*.

Biofuel.[3&7] Gas or liquid fuel made from plant material (biomass). Includes wood, wood waste, wood liquors, peat, railroad ties, wood sludge, spent sulfite liquors, agricultural waste, straw, tires, fish oils, tall oil, sludge waste, waste alcohol, municipal solid waste, landfill gases, other waste, and ethanol blended into motor gasoline.

Biogeochemical cycle.[7] Natural processes that recycle nutrients in various chemical forms from the environment, to organisms, and then back to the environment. Examples are the carbon, oxygen, nitrogen, phosphorus, and hydrologic cycles.

Biological oxygen demand (BOD).[7] Amount of dissolved oxygen needed by aerobic decomposers to break down the organic materials in a given volume of water at a certain temperature over a specified time period. See *BOD5*.

Biomass.[7] Total dry weight of all living organisms that can be supported at each tropic level in a food chain. Also, materials that are biological in origin, including organic material (both living and dead) from above and below ground, for example, trees, crops, grasses, tree litter, roots, and animals and animal waste.

Biomass energy.[1] Energy produced by combusting biomass materials such as wood. The carbon dioxide emitted from burning biomass will not increase total atmospheric carbon dioxide if this consumption is done on a sustainable basis (i.e., if in a given period of time, regrowth of biomass takes up as much carbon dioxide as is released from biomass combustion). Biomass energy is often suggested as a replacement for fossil fuel combustion.

Biosphere.[2&7] The living and dead organisms found near the earth's surface in parts of the lithosphere, atmosphere, and hydrosphere. The part of the global carbon cycle that includes living organisms and biogenic organic matter.

Biotic.[7] Living. Living organisms make up the biotic parts of ecosystems. See *abiotic*.

Bitumen.[7] Gooey, black, high-sulfur, heavy oil extracted from tar sand and then upgraded to synthetic fuel oil. See *tar sand*.

Bituminous coal.[2] A dense, black, soft coal, often with well-defined bands of bright and dull material. The most common coal, with moisture content usually less than 20 percent. Used for generating electricity, making coke, and space heating.

BOD5.[2] The biochemical oxygen demand of wastewater during decomposition occurring over a 5-day period. A measure of the organic content of wastewater. See *biological oxygen demand*.

British thermal unit (Btu).[3] The quantity of heat required to raise the temperature of one pound of water one degree of Fahrenheit at or near 39.2 degrees Fahrenheit.

Bunker fuel.[2] Fuel supplied to ships and aircraft for international transportation, irrespective of the flag of the carrier, consisting primarily of residual and distillate fuel oil for ships and jet fuel for aircraft.

Bus.[6&8] A rubber-tired, self-propelled, manually steered vehicle that is generally designed to transport 30 individuals or more. Bus types include intercity, school and transit.

Carbon black.[2] An amorphous form of carbon, produced commercially by thermal or oxidative decomposition of hydrocarbons and used principally in rubber goods, pigments, and printer's ink.

Carbon cycle.[2] All carbon reservoirs and exchanges of carbon from reservoir to reservoir by various chemical, physical, geological, and biological processes. Usually thought of as a series of the four main reservoirs of carbon interconnected by pathways of exchange. The four reservoirs, regions of the Earth in which carbon behaves in a systematic manner, are the atmosphere, terrestrial biosphere (usually includes freshwater systems), oceans, and sediments (includes fossil fuels). Each of these global reservoirs may be subdivided into smaller pools, ranging in size from individual communities or ecosystems to the total of all living organisms (biota).

Carbon dioxide.[2] A colorless, odorless, non-poisonous gas that is a normal part of the ambient air. Carbon dioxide is a product of fossil fuel combustion. Although carbon dioxide does not directly impair human health, it is a greenhouse gas that traps terrestrial (i.e., infrared) radiation and contributes to the potential for global warming. See *global warming*.

Carbon equivalent (CE).[1] A metric measure used to compare the emissions of the different greenhouse gases based upon their global warming potential (GWP). Greenhouse gas emissions in the United States are most commonly expressed as "million metric tons of carbon equivalents" (MMTCE). Global warming potentials are used to convert greenhouse gases to carbon dioxide equivalents. See *global warming potential, greenhouse gas*.

Carbon flux.[9] The rate of exchange of carbon between pools (i.e., reservoirs).

Carbon intensity. The relative amount of carbon emitted per unit of energy or fuels consumed.

Carbon pool.[9] The reservoir containing carbon as a principal element in the geochemical cycle.

Carbon sequestration.[1] The uptake and storage of carbon. Trees and plants, for example, absorb carbon dioxide, release the oxygen and store the carbon. Fossil fuels were at one time biomass and continue to store the carbon until burned. See *carbon sinks*.

Carbon sinks.[1] Carbon reservoirs and conditions that take-in and store more carbon (i.e., carbon sequestration) than they release. Carbon sinks can serve to partially offset greenhouse gas emissions. Forests and oceans are large carbon sinks. See *carbon sequestration*.

Carbon tetrachloride (CCl_4).[11] A compound consisting of one carbon atom and four chlorine atoms. It is an ozone depleting substance. Carbon tetrachloride was widely used as a raw material in many industrial applications, including the production of chlorofluorocarbons, and as a solvent. Solvent use was ended in the United States when it was discovered to be carcinogenic. See *ozone depleting substance*.

Chemical reaction. [7] Interaction between chemicals in which there is a change in the chemical composition of the elements or compounds involved.

Chlorofluorocarbons (CFCs). [7] Organic compounds made up of atoms of carbon, chlorine, and fluorine. An example is CFC-12 (CCl_2F_2), used as a refrigerant in refrigerators and air conditioners and as a foam blowing agent. Gaseous CFCs can deplete the ozone layer when they slowly rise into the stratosphere, are broken down by strong ultraviolet radiation, release chlorine atoms, and then react with ozone molecules. See *Ozone Depleting Substance.*

Climate. [1&9] The average weather, usually taken over a 30 year time period, for a particular region and time period. Climate is not the same as weather, but rather, it is the average pattern of weather for a particular region. Weather describes the short-term state of the atmosphere. Climatic elements include precipitation, temperature, humidity, sunshine, wind velocity, phenomena such as fog, frost, and hail-storms, and other measures of the weather. See *weather*.

Climate change. [1] The term “climate change” is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, “climate change” has been used synonymously with the term, “global warming”; scientists however, tend to use the term in the wider sense to also include natural changes in climate. See *global warming, greenhouse effect, enhanced greenhouse effect, radiative forcing.*

Climate feedback. [1] An atmospheric, oceanic, terrestrial, or other process that is activated by direct climate change induced by changes in radiative forcing. Climate feedbacks may increase (positive feedback) or diminish (negative feedback) the magnitude of the direct climate change.

Climate lag. [1] The delay that occurs in climate change as a result of some factor that changes very slowly. For example, the effects of releasing more carbon dioxide into the atmosphere may not be known for some time because a large fraction is dissolved in the ocean and only released to the atmosphere many years later.

Climate sensitivity. [1] The equilibrium response of the climate to a change in radiative forcing; for example, a doubling of the carbon dioxide concentration. See *radiative forcing*.

Climate system (or Earth system). [1] The atmosphere, the oceans, the biosphere, the cryosphere, and the geosphere, together make up the climate system.

Coal. [2] A black or brownish black solid, combustible substance formed by the partial decomposition of vegetable matter without access to air. The rank of coal, which includes anthracite, bituminous coal, subbituminous coal, and lignite, is based on fixed carbon, volatile matter, and heating value. Coal rank indicates the progressive alteration, or coalification, from lignite to anthracite. See *anthracite, bituminous coal, subbituminous coal, lignite*.

Coal coke. [2] A hard, porous product made from baking bituminous coal in ovens at temperatures as high as 2,000 degrees Fahrenheit. It is used both as a fuel and as a reducing agent in smelting iron ore in a blast furnace.

Coal gasification. [7] Conversion of solid coal to synthetic natural gas (SNG) or a gaseous mixture that can be burned as a fuel.

Coal liquefaction. [7] Conversion of solid coal to a liquid fuel such as synthetic crude oil or methanol.

Coalbed methane. [2] Methane that is produced from coalbeds in the same manner as natural gas produced from other strata. Methane is the principal component of natural gas.

Co-control benefit. [10] It is the additional benefit derived from an environmental policy that is designed to control one type of pollution, while reducing the emissions of other pollutants as well. For example, a policy to reduce carbon dioxide emissions might reduce the combustion of coal, but when coal combustion is reduced, so too are the emissions of particulates and sulfur dioxide. The benefits associated with reductions in emissions of particulates and sulfur dioxide are the co-control benefits of reductions in carbon dioxide.

Cogeneration. [7] Production of two useful forms of energy such as high-temperature heat and electricity from the same process.

Combustion. [2] Chemical oxidation accompanied by the generation of light and heat.

Commercial sector.[8] An area consisting of non-housing units such as non-manufacturing business establishments (e.g., wholesale and retail businesses), health and educational institutions, and government offices.

Compost. [7] Partially decomposed organic plant and animal matter that can be used as a soil conditioner or fertilizer.

Composting. [7] Partial breakdown of organic plant and animal matter by aerobic bacteria to produce a material that can be used as a soil conditioner or fertilizer. See *compost.*

Compound. [7] Combination of two or more different chemical elements held together by chemical bonds. See *element*. See *inorganic compound, organic compound*.

Concentration. [7] Amount of a chemical in a particular volume or weight of air, water, soil, or other medium. See *parts per billion, parts per million.*

Conference Of Parties (COP). [10] The supreme body of the United Nations Framework Convention on Climate Change (UNFCCC). It comprises more than 170 nations that have ratified the Convention. Its first session was held in Berlin, Germany, in 1995 and is expected to continue meeting on a yearly basis. The COP's role is to promote and review the implementation of the Convention. It will periodically review existing commitments in light of the Convention's objective, new scientific findings, and the effectiveness of national climate change programs. See *United Nations Framework Convention on Climate Change.*

Conifer. [7] See *coniferous trees*.

Coniferous trees. [7] Cone-bearing trees, mostly evergreens, that have needle-shaped or scale-like leaves. They produce wood known commercially as softwood. See *deciduous trees.*

Criteria pollutant. [2] A pollutant determined to be hazardous to human health and regulated under EPA's National Ambient Air Quality Standards. The 1970 amendments to the Clean Air Act require EPA to describe the health and welfare impacts of a pollutant as the "criteria" for inclusion in the regulatory regime. In this report, emissions of the criteria pollutants CO, NO_x, NMVOCs, and SO_2 are reported because they are thought to be precursors to greenhouse gas formation.

Crop residue. [2] Organic residue remaining after the harvesting and processing of a crop.

Crop rotation. [7] Planting the same field or areas of fields with different crops from year to year to reduce depletion of soil nutrients. A plant such as corn, tobacco, or cotton, which remove large amounts of nitrogen from the soil, is planted one year. The next year a legume such as soybeans, which add nitrogen to the soil, is planted.

Crude oil. [2] A mixture of hydrocarbons that exist in liquid phase in underground reservoirs and remain liquid at atmospheric pressure after passing through surface separating facilities. See *petroleum.*

Deciduous trees. [7] Trees such as oaks and maples that lose their leaves during part of the year. See *coniferous trees*.

Decomposition. [9] The breakdown of matter by bacteria and fungi. It changes the chemical composition and physical appearance of the materials.

Deforestation. [1] Those practices or processes that result in the conversion of forested lands for non-forest uses. This is often cited as one of the major causes of the enhanced greenhouse effect for two reasons: 1) the burning or decomposition of the wood releases carbon dioxide; and 2) trees that once removed carbon dioxide from the atmosphere in the process of photosynthesis are no longer present.

Degradable. [7] See *biodegradable*.

Desertification. [1] The progressive destruction or degradation of existing vegetative cover to form a desert. This can occur due to overgrazing, deforestation, drought, and the burning of extensive areas. Once formed, deserts can only support a sparse range of vegetation. Climatic effects associated with this phenomenon include increased reflectivity of solar radiation, reduced atmospheric humidity, and greater atmospheric dust (aerosol) loading.

Distillate fuel oil. [2] A general classification for the petroleum fractions produced in conventional distillation operations. Included are products known as No. 1, No. 2, and No. 4 fuel oils and No. 1, No. 2, and No. 4 diesel fuels. Used primarily for space heating, on and off-highway diesel engine fuel (including railroad engine fuel and fuel for agricultural machinery), and electric power generation.

Economy. [7] System of production, distribution, and consumption of economic goods.

Ecosystem. [10] The complex system of plant, animal, fungal, and microorganism communities and their associated non-living environment interacting as an ecological unit. Ecosystems have no fixed boundaries; instead their parameters are set to the scientific, management, or policy question being examined. Depending upon the purpose of analysis, a single lake, a watershed, or an entire region could be considered an ecosystem.

Electrons. [7] Tiny particle moving around outside the nucleus of an atom. Each electron has one unit of negative charge (-) and almost no mass.

Element. [7] Chemicals such as hydrogen (H), iron (Fe), sodium (Na), carbon (C), nitrogen (N), or oxygen (O), whose distinctly different atoms serve as the basic building blocks of all matter. There are 92 naturally occurring elements. Another 15 have been made in laboratories. Two or more elements combine to form compounds that make up most of the world's matter. See *compound*.

Emission inventory. A list of air pollutants emitted into a community's, state's, nation's, or the Earth's atmosphere in amounts per some unit time (e.g. day or year) by type of source. An emission inventory has both political and scientific applications.

Emissions coefficient/factor. [2] A unique value for scaling emissions to activity data in terms of a standard rate of emissions per unit of activity (e.g., grams of carbon dioxide emitted per barrel of fossil fuel consumed).

Emissions. [2] Releases of gases to the atmosphere (e.g., the release of carbon dioxide during fuel combustion). Emissions can be either intended or unintended releases. See *fugitive emissions.*

Energy conservation. [7] Reduction or elimination of unnecessary energy use and waste. See *energy-efficiency*.

Energy intensity. [5] Ratio between the consumption of energy to a given quantity of output; usually refers to the amount of primary or final energy consumed per unit of gross domestic product.

Energy quality. [7] Ability of a form of energy to do useful work. High-temperature heat and the chemical energy in fossil fuels and nuclear fuels are concentrated high quality energy. Low-quality energy such as low-temperature heat is dispersed or diluted and cannot do much useful work.

Energy. [3] The capacity for doing work as measured by the capability of doing work (potential energy) or the conversion of this capability to motion (kinetic energy). Energy has several forms, some of which are easily convertible and can be changed to another form useful for work. Most of the world's convertible energy comes from fossil fuels that are burned to produce heat that is then used as a transfer medium to mechanical or other means in order to accomplish tasks. In the United States, electrical energy is often measured in kilowatt-hours (kWh), while heat energy is often measured in British thermal units (Btu).

Energy-efficiency. [6&8] The ratio of the useful output of services from an article of industrial equipment to the energy use by such an article; for example, vehicle miles traveled per gallon of fuel (mpg).

Enhanced greenhouse effect. [1] The concept that the natural greenhouse effect has been enhanced by anthropogenic emissions of greenhouse gases. Increased concentrations of carbon dioxide, methane, and nitrous oxide, CFCs, HFCs, PFCs, SF_6, NF_3, and other photochemically important gases caused by human activities such as fossil fuel consumption, trap more infra-red radiation, thereby exerting a warming influence on the climate. See *greenhouse gas, anthropogenic, greenhouse effect, climate.*

Enhanced oil recovery. [7] Removal of some of the heavy oil left in an oil well after primary and secondary recovery. See *primary oil recovery, secondary oil recovery*.

Enteric fermentation.[2] A digestive process by which carbohydrates are broken down by microorganisms into simple molecules for absorption into the bloodstream of an animal.

Environment.[7] All external conditions that affect an organism or other specified system during its lifetime.

Ethanol (C_2H_5OH).[8] Otherwise known as ethyl alcohol, alcohol, or grain spirit. A clear, colorless, flammable oxygenated hydrocarbon with a boiling point of 78.5 degrees Celsius in the anhydrous state. In transportation, ethanol is used as a vehicle fuel by itself (E100), blended with gasoline (E85), or as a gasoline octane enhancer and oxygenate (10 percent concentration).

Evapotranspiration.[10] The loss of water from the soil by evaporation and by transpiration from the plants growing in the soil, which rises with air temperature.

Exponential growth.[7] Growth in which some quantity, such as population size, increases by a constant percentage of the whole during each year or other time period; when the increase in quantity over time is plotted, this type of growth yields a curve shaped like the letter J.

Feedlot.[7] Confined outdoor or indoor space used to raise hundreds to thousands of domesticated livestock. See *rangeland*.

Fertilization, carbon dioxide.[1] An expression (sometimes reduced to 'fertilization') used to denote increased plant growth due to a higher carbon dioxide concentration.

Fertilizer.[7] Substance that adds inorganic or organic plant nutrients to soil and improves its ability to grow crops, trees, or other vegetation. See *organic fertilizer*.

Flaring.[9] The burning of waste gases through a flare stack or other device before releasing them to the air.

Fluidized bed combustion (FBC).[7] Process for burning coal more efficiently, cleanly, and cheaply. A stream of hot air is used to suspend a mixture of powdered coal and limestone during combustion. About 90 to 98 percent of the sulfur dioxide produced during combustion is removed by reaction with limestone to produce solid calcium sulfate.

Fluorocarbons.[1] Carbon-fluorine compounds that often contain other elements such as hydrogen, chlorine, or bromine. Common fluorocarbons include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs). See *chlorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, perfluorocarbons.*

Forcing mechanism.[1] A process that alters the energy balance of the climate system (i.e., changes the relative balance between incoming solar radiation and outgoing infrared radiation from Earth). Such mechanisms include changes in solar irradiance, volcanic eruptions, and enhancement of the natural greenhouse effect by emission of carbon dioxide.

Forest.[7] Terrestrial ecosystem (biome) with enough average annual precipitation (at least 76 centimeters or 30 inches) to support growth of various species of trees and smaller forms of vegetation.

Fossil fuel. A general term for buried combustible geologic deposits of organic materials, formed from decayed plants and animals that have been converted to crude oil, coal, natural gas, or heavy oils by exposure to heat and pressure in the earth's crust over hundreds of millions of years. See *coal, petroleum, crude oil, natural gas*.

Fossil fuel combustion.[1] Burning of coal, oil (including gasoline), or natural gas. The burning needed to generate energy release carbon dioxide by-products that can include unburned hydrocarbons, methane, and carbon monoxide. Carbon monoxide, methane, and many of the unburned hydrocarbons slowly oxidize into carbon dioxide in the atmosphere. Common sources of fossil fuel combustion include cars and electric utilities.

Freon. See *chlorofluorocarbon*.

Fugitive emissions.[2] Unintended gas leaks from the processing, transmission, and/or transportation of fossil fuels, CFCs from refrigeration leaks, SF_6 from electrical power distributor, etc.

Gasohol.[7] Vehicle fuel consisting of a mixture of gasoline and ethyl or methyl alcohol; typically 10 to 23 percent ethanol by volume.

General Aviation.[8] That portion of civil aviation, which encompasses all facets of aviation except air carriers. It includes any air taxis, commuter air carriers, and air travel clubs, which do not hold Certificates of Public Convenience and Necessity. See *air carriers*.

General circulation model (GCM).[1] A global, three-dimensional computer model of the climate system which can be used to simulate human-induced climate change. GCMs are highly complex and they represent the effects of such factors as reflective and absorptive properties of atmospheric water vapor, greenhouse gas concentrations, clouds, annual and daily solar heating, ocean temperatures and ice boundaries. The most recent GCMs include global representations of the atmosphere, oceans, and land surface.

Geosphere. [1] The soils, sediments, and rock layers of the Earth's crust, both continental and beneath the ocean floors.

Geothermal energy. [7] Heat transferred from the earth's molten core to under-ground deposits of dry steam (steam with no water droplets), wet steam (a mixture of steam and water droplets), hot water, or rocks lying fairly close to the earth's surface.

Global Warming Potential (GWP). [1] The index used to translate the level of emissions of various gases into a common measure in order to compare the relative radiative forcing of different gases without directly calculating the changes in atmospheric concentrations. GWPs are calculated as the ratio of the radiative forcing that would result from the emissions of one kilogram of a greenhouse gas to that from the emission of one kilogram of carbon dioxide over a period of time (usually 100 years). Gases involved in complex atmospheric chemical processes have not been assigned GWPs. See *lifetime*.

Global warming. [10] The progressive gradual rise of the earth's surface temperature thought to be caused by the greenhouse effect and responsible for changes in global climate patterns. See *enhanced greenhouse effect, greenhouse effect, climate change.*

Grassland. [7] Terrestrial ecosystem (biome) found in regions where moderate annual average precipitation (25 to 76 centimeters or 10 to 30 inches) is enough to support the growth of grass and small plants but not enough to support large stands of trees.

Greenhouse effect. [7] Trapping and build-up of heat in the atmosphere (troposphere) near the earth's surface. Some of the heat flowing back toward space from the earth's surface is absorbed by water vapor, carbon dioxide, ozone, and several other gases in the atmosphere and then reradiated back toward the earth's surface. If the atmospheric concentrations of these greenhouse gases rise, the average temperature of the lower atmosphere will gradually increase. See *enhanced greenhouse effect, climate change, global warming.*

Greenhouse gas (GHG). [1] Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include, but are not limited to, water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrochlorofluorocarbons (HCFCs), ozone (O_3), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). See *carbon dioxide, methane, nitrous oxide, hydrochlorofluorocarbon, ozone, hydrofluorocarbon, perfluorocarbon, sulfur hexafluoride.*

Halocarbons. [1] Chemicals consisting of carbon, sometimes hydrogen, and either chlorine, fluorine, bromine or iodine.

Halons. [1] Compounds, also known as bromofluorocarbons, that contain bromine, fluorine, and carbon. They are generally used as fire extinguishing agents and cause ozone depletion. Bromine is many times more effective at destroying stratospheric ozone than chlorine. See *ozone depleting substance*.

Heat content. [5] The amount of heat per unit mass released upon complete combustion.

Heat. [7] Form of kinetic energy that flows from one body to another when there is a temperature difference between the two bodies. Heat always flows spontaneously from a hot sample of matter to a colder sample of matter. This is one way to state the second law of thermodynamics. See *temperature*.

Higher heating value. [5] Quantity of heat liberated by the complete combustion of a unit volume or weight of a fuel assuming that the produced water vapor is completely condensed and the heat is recovered; also known as gross calorific value. See *lower heating value.*

Histosol. [9] Wet organic soils, such as peats and mucks.

Hydrocarbons. [1] Substances containing only hydrogen and carbon. Fossil fuels are made up of hydrocarbons. Some hydrocarbon compounds are major air pollutants.

Hydrochlorofluorocarbons (HCFCs). [1] Compounds containing hydrogen, fluorine, chlorine, and carbon atoms. Although ozone depleting substances, they are less potent at destroying stratospheric ozone than chlorofluorocarbons (CFCs). They have been introduced as temporary replacements for CFCs and are also greenhouse gases. See *ozone depleting substance.*

Hydroelectric power plant. [7] Structure in which the energy of fading or flowing water spins a turbine generator to produce electricity.

Hydrofluorocarbons (HFCs). [1] Compounds containing only hydrogen, fluorine, and carbon atoms. They were introduced as alternatives to ozone depleting substances in serving many industrial, commercial, and personal needs. HFCs are emitted as by-products of industrial processes and are also used in manufacturing. They do not significantly deplete the stratospheric ozone layer, but they are powerful greenhouse gases with global warming potentials ranging from 140 (HFC-152a) to 11,700 (HFC-23).

Hydrologic cycle. The process of evaporation, vertical and horizontal transport of vapor, condensation, precipitation, and the flow of water from continents to oceans. It is a major factor in determining climate through its influence on surface vegetation, the clouds, snow and ice, and soil moisture. The hydrologic cycle is responsible for 25 to 30 percent of the mid-latitudes' heat transport from the equatorial to polar regions.

Hydropower. [7] Electrical energy produced by falling or flowing water. See *hydroelectric power plant*.

Hydrosphere. [7] All the earth's liquid water (oceans, smaller bodies of fresh water, and underground aquifers), frozen water (polar ice caps, floating ice, and frozen upper layer of soil known as permafrost), and small amounts of water vapor in the atmosphere.

Industrial sector. [8] Construction, manufacturing, agricultural and mining establishments.

Infrared radiation. [1] The heat energy that is emitted from all solids, liquids, and gases. In the context of the greenhouse issue, the term refers to the heat energy emitted by the Earth's surface and its atmosphere. Greenhouse gases strongly absorb this radiation in the Earth's atmosphere, and re-radiate some of it back towards the surface, creating the greenhouse effect.

Inorganic compound. [7] Combination of two or more elements other than those used to form organic compounds. See *organic compound*.

Inorganic fertilizer. [7] See *synthetic fertilizer*.

Intergovernmental Panel on Climate Change (IPCC). [1] The IPCC was established jointly by the United Nations Environment Programme and the World Meteorological Organization in 1988. The purpose of the IPCC is to assess information in the scientific and technical literature related to all significant components of the issue of climate change. The IPCC draws upon hundreds of the world's expert scientists as authors and thousands as expert reviewers. Leading experts on climate change and environmental, social, and economic sciences from some 60 nations have helped the IPCC to prepare periodic assessments of the scientific underpinnings for understanding global climate change and its consequences. With its capacity for reporting on climate change, its consequences, and the viability of adaptation and mitigation measures, the IPCC is also looked to as the official advisory body to the world's governments on the state of the science of the climate change issue. For example, the IPCC organized the development of internationally accepted methods for conducting national greenhouse gas emission inventories.

Irreversibilities. [10] Changes that, once set in motion, cannot be reversed, at least on human time scales.

Jet fuel [8] Includes both naphtha-type and kerosene-type fuels meeting standards for use in aircraft turbine engines. Although most jet fuel is used in aircraft, some is used for other purposes such as generating electricity.

Joule. [1] The energy required to push with a force of one Newton for one meter.

Kerogen. [7] Solid, waxy mixture of hydrocarbons found in oil shale, with a fine grained sedimentary rock. When the rock is heated to high temperatures, the kerogen is vaporized. The vapor is condensed and then sent to a refinery to produce gasoline, heating oil, and other products. See *oil shale, shale oil*.

Kerosene. [2] A petroleum distillate that has a maximum distillation temperature of 401 degrees Fahrenheit at the 10 percent recovery point, a final boiling point of 572 degrees Fahrenheit, and a minimum flash point of 100 degrees Fahrenheit. Used in space heaters, cookstoves, and water heaters, and suitable for use as an illuminant when burned in wick lamps.

Kyoto Protocol. [10] This is an international agreement struck by 159 nations attending the Third Conference of Parties (COP) to the United Nations Framework Convention on Climate Change (held in December of 1997 in Kyoto Japan) to reduce worldwide emissions of greenhouse gases. If ratified and put into force, individual countries have committed to reduce their greenhouse gas emissions by a specified amount. See *Framework Convention on Climate Change, Conference of Parties.*

Landfill. [7] Land waste disposal site in which waste is generally spread in thin layers, compacted, and covered with a fresh layer of soil each day.

Lifetime (atmospheric). [1] The lifetime of a greenhouse gas refers to the approximate amount of time it would take for the anthropogenic increment to an atmospheric pollutant concentration to return to its natural level (assuming emissions cease) as a result of either being converted to another chemical compound or being taken out of the atmosphere via a sink. This time depends on the pollutant's sources and sinks as well as its reactivity. The lifetime of a pollutant is often considered in conjunction with the mixing of pollutants in the atmosphere; a long lifetime will allow the pollutant to mix throughout the atmosphere. Average lifetimes can vary from about a week (e.g., sulfate aerosols) to more than a century (e.g., CFCs, carbon dioxide). See *residence time.*

Light-duty vehicles. [8] Automobiles and light trucks combined.

Lignite. [2] A brownish-black coal of low rank with high inherent moisture and volatile matter content, used almost exclusively for electric power generation. Also referred to as brown coal.

Liquefied natural gas (LNG). [7] Natural gas converted to liquid form by cooling to a very low temperature.

Liquefied petroleum gas (LPG). [2] Ethane, ethylene, propane, propylene, normal butane, butylene, and isobutane produced at refineries or natural gas processing plants, including plants that fractionate new natural gas plant liquids.

Litter. [9] Undecomposed plant residues on the soil surface. See *decomposition*.

Longwave radiation. [9] The radiation emitted in the spectral wavelength greater than 4 micrometers corresponding to the radiation emitted from the Earth and atmosphere. It is sometimes referred to as terrestrial radiation or infrared radiation, although somewhat imprecisely. See *infrared radiation*.

Low Emission Vehicle (LEV). [8] A vehicle meeting the low-emission vehicle standards.

Lower heating value. [5] Quantity of heat liberated by the complete combustion of a unit volume or weight of a fuel assuming that the produced water remains as a vapor and the heat of the vapor is not recovered; also known as net calorific value. See *higher heating value.*

Lubricant. [2] A substance used to reduce friction between bearing surfaces or as a process material, either incorporated into other materials used as aids in manufacturing processes or as carriers of other materials. Petroleum lubricants may be produced either from distillates or residues. Other substances may be added to impart or improve useful properties. Does not include by-products of lubricating oil from solvent extraction or tars derived from de-asphalting. Lubricants include all grades of lubricating oils from spindle oil to cylinder oil and those used in greases. Lubricant categories are paraffinic and naphthenic.

Manure. [7] Dung and urine of animals that can be used as a form of organic fertilizer.

Mass balance. [9] The application of the principle of the conservation of matter.

Mauna Loa. [9] An intermittently active volcano 13,680 feet (4,170 meters) high in Hawaii.

Methane (CH_4). [1] A hydrocarbon that is a greenhouse gas with a global warming potential most recently estimated at 21. Methane is produced through anaerobic (without oxygen) decomposition of waste in landfills, animal digestion, decomposition of animal wastes, production and distribution of natural gas and petroleum, coal production, and incomplete fossil fuel combustion. The atmospheric concentration of methane as been shown to be increasing at a rate of about 0.6 percent per year and the concentration of about 1.7 per million by volume (ppmv) is more than twice its pre-industrial value. However, the rate of increase of methane in the atmosphere may be stabilizing.

Methanol (CH_3OH). [8] A colorless poisonous liquid with essentially no odor and little taste. It is the simplest alcohol with a boiling point of 64.7 degrees Celsius. In transportation, methanol is used as a vehicle fuel by itself (M100), or blended with gasoline (M85).

Methanotrophic. [7] Having the biological capacity to oxidize methane to CO_2 and water by metabolism under aerobic conditions. See *aerobic.*

Methyl bromide (CH_3Br). [11] An effective pesticide; used to fumigate soil and many agricultural products. Because it contains bromine, it depletes stratospheric ozone when released to the atmosphere. See *ozone depleting substance.*

Metric ton. [1] Common international measurement for the quantity of greenhouse gas emissions. A metric ton is equal to 1000 kilograms, 2204.6 pounds, or 1.1023 short tons.

Mineral. [7] Any naturally occurring inorganic substance found in the earth's crust as a crystalline solid.

Model year. [8] Refers to the "sales" model year; for example, vehicles sold during the period from October 1 to the next September 31 is considered one model year.

Molecule. [7] Chemical combination of two or more atoms of the same chemical element (such as O_2) or different chemical elements (such as H_2O).

Montreal Protocol on Substances that Deplete the Ozone Layer. [11] The Montreal Protocol and its amendments control the phaseout of ozone depleting substances production and use. Under the Protocol, several international organizations report on the science of ozone depletion, implement projects to help move away from ozone depleting substances, and provide a forum for policy discussions. In the United States, the Protocol is implemented under the rubric of the Clean Air Act Amendments of 1990. See *ozone depleting substance, ozone layer*.

Motor gasoline. [2] A complex mixture of relatively volatile hydrocarbons, with or without small quantities of additives, obtained by blending appropriate refinery streams to form a fuel suitable for use in spark-ignition engines. Motor gasoline includes both leaded and unleaded grades of finished gasoline, blending components, and gasohol.

Municipal solid waste (MSW). [2] Residential solid waste and some non-hazardous commercial, institutional, and industrial wastes. This material is generally sent to municipal landfills for disposal. See *landfill.*

Naphtha. [2] A generic term applied to a petroleum fraction with an approximate boiling range between 122 and 400 degrees Fahrenheit.

Natural gas. [7] Underground deposits of gases consisting of 50 to 90 percent methane (CH_4) and small amounts of heavier gaseous hydrocarbon compounds such as propane (C_3H_4) and butane (C_4H_{10}).

Natural gas liquids (NGLs). [2] Those hydrocarbons in natural gas that are separated as liquids from the gas. Includes natural gas plant liquids and lease condensate.

Nitrogen cycle. [7] Cyclic movement of nitrogen in different chemical forms from the environment, to organisms, and then back to the environment.

Nitrogen fixation. [7] Conversion of atmospheric nitrogen gas into forms useful to plants and other organisms by lightning, bacteria, and blue-green algae; it is part of the nitrogen cycle.

Nitrogen oxides (NO_x). [1] Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules. Nitrogen oxides are produced, for example, by the combustion of fossil fuels in vehicles and electric power plants. In the atmosphere, nitrogen oxides can contribute to formation of photochemical ozone (smog), impair visibility, and have health consequences; they are considered pollutants.

Nitrous oxide (N_2O). [1] A powerful greenhouse gas with a global warming potential most recently evaluated at 310. Major sources of nitrous oxide include soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

Nonbiodegradable. [7] Substance that cannot be broken down in the environment by natural processes. See *biodegradable*.

Nonlinearities. [10] Occur when changes in one variable cause a more than proportionate impact on another variable.

Non-methane volatile organic compounds (NMVOCs). [2] Organic compounds, other than methane, that participate in atmospheric photochemical reactions.

Non-point source. [7] Large land area such as crop fields and urban areas that discharge pollutant into surface and underground water over a large area. See *point source*.

Nuclear electric power. [3] Electricity generated by an electric power plant whose turbines are driven by steam generated in a reactor by heat from the fissioning of nuclear fuel.

Nuclear energy. [7] Energy released when atomic nuclei undergo a nuclear reaction such as the spontaneous emission of radioactivity, nuclear fission, or nuclear fusion.

Oil shale. [7] Underground formation of a fine-grained sedimentary rock containing varying amounts of kerogen, a solid, waxy mixture of hydrocarbon compounds. Heating the rock to high temperatures converts the kerogen to a vapor, which can be condensed to form a slow flowing heavy oil called shale oil. See *kerogen, shale oil*.

Oil. See *crude oil, petroleum.*

Ore. [7] Mineral deposit containing a high enough concentration of at least one metallic element to permit the metal to be extracted and sold at a profit.

Organic compound. [7] Molecule that contains atoms of the element carbon, usually combined with itself and with atoms of one or more other element such as hydrogen, oxygen, nitrogen, sulfur, phosphorus, chlorine, or fluorine. See *inorganic compound*.

Organic fertilizer. [7] Organic material such as manure or compost, applied to cropland as a source of plant nutrients.

Oxidize. [2] To chemically transform a substance by combining it with oxygen.

Oxygen cycle. [7] Cyclic movement of oxygen in different chemical forms from the environment, to organisms, and then back to the environment.

Ozone. [6] A colorless gas with a pungent odor, having the molecular form of O_3, found in two layers of the atmosphere, the stratosphere and the troposphere. Ozone is a form of oxygen found naturally in the stratosphere that provides a protective layer shielding the Earth from ultraviolet radiation's harmful health effects on humans and the environment. In the troposphere, ozone is a chemical oxidant and major component of photochemical smog. Ozone can seriously affect the human respiratory system.

Ozone Depleting Substance (ODS). [11] A family of man-made compounds that includes, but are not limited to, chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These compounds have been shown to deplete stratospheric ozone, and therefore are typically referred to as ODSs.

Ozone layer. [7] Layer of gaseous ozone (O_3) in the stratosphere that protects life on earth by filtering out harmful ultraviolet radiation from the sun. See *stratosphere, ultraviolet radiation*.

Ozone precursors. [2] Chemical compounds, such as carbon monoxide, methane, non-methane hydrocarbons, and nitrogen oxides, which in the presence of solar radiation react with other chemical compounds to form ozone, mainly in the troposphere. See *troposphere*

Particulate matter (PM). [7] Solid particles or liquid droplets suspended or carried in the air.

Particulates. See *particulate matter*.

Parts per billion (ppb). [7] Number of parts of a chemical found in one billion parts of a particular gas, liquid, or solid mixture. See *concentration.*

Parts per million (ppm). [7] Number of parts of a chemical found in one million parts of a particular gas, liquid, or solid. See *concentration.*

Pentanes plus. [2] A mixture of hydrocarbons, mostly pentanes and heavier fractions, extracted from natural gas.

Perfluorocarbons (PFCs). [1] A group of human-made chemicals composed of carbon and fluorine only. These chemicals (predominantly CF_4 and C_2F_6) were introduced as alternatives, along with hydrofluorocarbons, to the ozone depleting substances. In addition, PFCs are emitted as by-products of industrial processes and are also used in manufacturing. PFCs do not harm the stratospheric ozone layer, but they are powerful greenhouse gases: CF_4 has a global warming potential (GWP) of 6,500 and C_2F_6 has a GWP of 9,200.

Petrochemical feedstock. [2] Feedstock derived from petroleum, used principally for the manufacture of chemicals, synthetic rubber, and a variety of plastics. The categories reported are naphtha (endpoint less than 401 degrees Fahrenheit) and other oils (endpoint equal to or greater than 401 degrees Fahrenheit).

Petrochemicals. [7] Chemicals obtained by refining (i.e., distilling) crude oil. They are used as raw materials in the manufacture of most industrial chemicals, fertilizers, pesticides, plastics, synthetic fibers, paints, medicines, and many other products. See *crude oil.*

Petroleum coke. [2] A residue that is the final product of the condensation process in cracking.

Petroleum. [2] A generic term applied to oil and oil products in all forms, such as crude oil, lease condensate, unfinished oils, petroleum products, natural gas plant liquids, and non-hydrocarbon compounds blended into finished petroleum products. See *crude oil.*

Photosynthesis. [7] Complex process that takes place in living green plant cells. Radiant energy from the sun is used to combine carbon dioxide (CO_2) and water (H_2O) to produce oxygen (O_2) and simple nutrient molecules, such as glucose ($C_6H_{12}O_6$).

Photovoltaic and solar thermal energy. [2] Energy radiated by the sun as electromagnetic waves (electromagnetic radiation) that is converted into electricity by means of solar (i.e., photovoltaic) cells or useable heat by concentrating (i.e., focusing) collectors.

Point source. [7] A single identifiable source that discharges pollutants into the environment. Examples are smokestack, sewer, ditch, or pipe. See *non-point source*.

Pollution. [7] A change in the physical, chemical, or biological characteristics of the air, water, or soil that can affect the health, survival, or activities of humans in an unwanted way. Some expand the term to include harmful effects on all forms of life.

Polyvinyl chloride (PVC). [2] A polymer of vinyl chloride. It is tasteless, odorless and insoluble in most organic solvents. A member of the family vinyl resin, used in soft flexible films for food packaging and in molded rigid products, such as pipes, fibers, upholstery, and bristles.

Population. [7] Group of individual organisms of the same species living within a particular area.

Prescribed burning. [7] Deliberate setting and careful control of surface fires in forests to help prevent more destructive fires and to kill off unwanted plants that compete with commercial species for plant nutrients; may also be used on grasslands.

Primary oil recovery. [7] Pumping out the crude oil that flows by gravity into the bottom of an oil well. See *enhanced oil recovery, secondary oil recovery*.

Quad. [8] Quad stands for quadrillion, which is, 10^{15}.

Radiation. [1] Energy emitted in the form of electromagnetic waves. Radiation has differing characteristics depending upon the wavelength. Because the radiation from the Sun is relatively energetic, it has a short wavelength (e.g., ultraviolet, visible, and near infrared) while energy re-radiated from the Earth's surface and the atmosphere has a longer wavelength (e.g., infrared radiation) because the Earth is cooler than the Sun. See *ultraviolet radiation, infrared radiation, solar radiation, longwave radiation, terrestrial radiation.*

Radiative forcing. [1] A change in the balance between incoming solar radiation and outgoing infrared (i.e., thermal) radiation. Without any radiative forcing, solar radiation coming to the Earth would continue to be approximately equal to the infrared radiation emitted from the Earth. The addition of greenhouse gases to the atmosphere traps an increased fraction of the infrared radiation, reradiating it back toward the surface of the Earth and thereby creates a warming influence.

Rail. [8] Includes “heavy” and “light” transit rail. Heavy transit rail is characterized by exclusive rights-of-way, multi-car trains, high speed rapid acceleration, sophisticated signaling, and high platform loading. Also known as subway, elevated railway, or metropolitan railway (metro). Light transit rail may be on exclusive or shared rights of way, high or low platform, multi-car trains or single cars, automated or manually operated. In generic usage, light rail includes streetcars, trolley cars, and tramways.

Rangeland. [7] Land, mostly grasslands, whose plants can provide food (i.e., forage) for grazing or browsing animals. See *feedlot*.

Recycling. [7] Collecting and reprocessing a resource so it can be used again. An example is collecting aluminum cans, melting them down, and using the aluminum to make new cans or other aluminum products.

Reforestation. [2] Replanting of forests on lands that have recently been harvested.

Renewable energy. [2] Energy obtained from sources that are essentially inexhaustible, unlike, for example, the fossil fuels, of which there is a finite supply. Renewable sources of energy include wood, waste, geothermal, wind, photovoltaic, and solar thermal energy. See *hydropower, photovoltaic*.

Residence time. [1] Average time spent in a reservoir by an individual atom or molecule. Also, this term is used to define the age of a molecule when it leaves the reservoir. With respect to greenhouse gases, residence time usually refers to how long a particular molecule remains in the atmosphere. See *lifetime.*

Residential sector. [3] An area or portion consisting only of housing units.

Residual fuel oil. [2] The heavier oils that remain after the distillate fuel oils and lighter hydrocarbons are distilled away in refinery operations and that conform to ASTM Specifications D396 and D975. Included are No. 5, a residual fuel oil of medium viscosity; Navy Special, for use in steam-powered vessels in government service and in shore power plants; and No. 6, which includes Bunker C fuel oil and is used for commercial and industrial heating, electricity generation, and to power ships. Imports of residual fuel oil include imported crude oil burned as fuel.

Secondary oil recovery. [7] Injection of water into an oil well after primary oil recovery to force out some of the remaining thicker crude oil. See *enhanced oil recovery, primary oil recovery.*

Sector. Division, most commonly used to denote type of energy consumer (e.g., residential) or according to the Intergovernmental Panel on Climate Change, the type of greenhouse gas emitter (e.g. industrial process). See *Intergovernmental Panel on Climate Change.*

Septic tank. [7] Underground tank for treatment of wastewater from a home in rural and suburban areas. Bacteria in the tank decompose organic wastes and the sludge settles to the bottom of the tank. The effluent flows out of the tank into the ground through a field of drainpipes.

Sewage treatment (primary). [7] Mechanical treatment of sewage in which large solids are filtered out by screens and suspended solids settle out as sludge in a sedimentation tank.

Shale oil. [7] Slow-flowing, dark brown, heavy oil obtained when kerogen in oil shale is vaporized at high temperatures and then condensed. Shale oil can be refined to yield gasoline, heating oil, and other petroleum products. See *kerogen, oil shale.*

Short ton. [1] Common measurement for a ton in the United States. A short ton is equal to 2,000 lbs. or 0.907 metric tons.

Sink. [1] A reservoir that uptakes a pollutant from another part of its cycle. Soil and trees tend to act as natural sinks for carbon.

Sludge. [7] Gooey solid mixture of bacteria and virus laden organic matter, toxic metals, synthetic organic chemicals, and solid chemicals removed from wastewater at a sewage treatment plant.

Soil. [7] Complex mixture of inorganic minerals (i.e., mostly clay, silt, and sand), decaying organic matter, water, air, and living organisms.

Soil carbon. [9] A major component of the terrestrial biosphere pool in the carbon cycle. The amount of carbon in the soil is a function of the historical vegetative cover and productivity, which in turn is dependent in part upon climatic variables.

Solar energy. [7] Direct radiant energy from the sun. It also includes indirect forms of energy such as wind, falling or flowing water (hydropower), ocean thermal gradients, and biomass, which are produced when direct solar energy interact with the earth. See *solar radiation.*

Solar radiation. [1] Energy from the Sun. Also referred to as short-wave radiation. Of importance to the climate system, solar radiation includes ultra-violet radiation, visible radiation, and infrared radiation.

Source. [4] Any process or activity that releases a greenhouse gas, an aerosol, or a precursor of a greenhouse gas into the atmosphere.

Special naphtha. [2] All finished products within the naphtha boiling range that are used as paint thinners, cleaners, or solvents. Those products are refined to a specified flash point.

Still gas. [2] Any form or mixture of gases produced in refineries by distillation, cracking, reforming, and other processes. Principal constituents are methane, ethane, ethylene, normal butane, butylene, propane, propylene, etc. Used as a refinery fuel and as a petrochemical feedstock.

Stratosphere. [7] Second layer of the atmosphere, extending from about 19 to 48 kilometers (12 to 30 miles) above the earth's surface. It contains small amounts of gaseous ozone (O_3), which filters out about 99 percent of the incoming harmful ultraviolet (UV) radiation. Most commercial airline flights operate at a cruising altitude in the lower stratosphere. See *ozone layer, ultraviolet radiation.*

Stratospheric ozone. See *ozone layer*.

Strip mining. [7] Cutting deep trenches to remove minerals such as coal and phosphate found near the earth's surface in flat or rolling terrain. See *surface mining*.

Subbituminous coal. [2] A dull, black coal of rank intermediate between lignite and bituminous coal.

Sulfur cycle. [7] Cyclic movement of sulfur in different chemical forms from the environment, to organisms, and then back to the environment.

Sulfur dioxide (SO_2). [1] A compound composed of one sulfur and two oxygen molecules. Sulfur dioxide emitted into the atmosphere through natural and anthropogenic processes is changed in a complex series of chemical reactions in the atmosphere to sulfate aerosols. These aerosols are believed to result in negative radiative forcing (i.e., tending to cool the Earth's surface) and do result in acid deposition (e.g., acid rain). See *aerosols, radiative forcing, acid deposition, acid rain.*

Sulfur hexafluoride (SF_6). [1] A colorless gas soluble in alcohol and ether, slightly soluble in water. A very powerful greenhouse gas used primarily in electrical transmission and distribution systems and as a dielectric in electronics. The global warming potential of SF_6 is 23,900. See *Global Warming Potential.*

Surface mining. [7] Removal of soil, sub-soil, and other strata and then extracting a mineral deposit found fairly close to the earth's surface. See *strip mining.*

Synthetic fertilizer. [7] Commercially prepared mixtures of plant nutrients such as nitrates, phosphates, and potassium applied to the soil to restore fertility and increase crop yields. See *organic fertilizer*.

Synthetic natural gas (SNG). [3] A manufactured product chemically similar in most respects to natural gas, resulting from the conversion or reforming of petroleum hydrocarbons. It may easily be substituted for, or interchanged with, pipeline quality natural gas.

Tailings. [7] Rock and other waste materials removed as impurities when minerals are mined and mineral deposits are processed. These materials are usually dumped on the ground or into ponds.

Tar sand. [7] Swamp-like deposit of a mixture of fine clay, sand, water, and variable amounts of tar-like heavy oil known as bitumen. Bitumen can be extracted from tar sand by heating. It can then be purified and upgraded to synthetic crude oil. See *bitumen*.

Temperature. [7] Measure of the average speed of motion of the atoms or molecules in a substance or combination of substances at a given moment. See *heat*.

Terrestrial. [7] Pertaining to land.

Terrestrial radiation. [9] The total infrared radiation emitted by the Earth and its atmosphere in the temperature range of approximately 200 to 300 Kelvin. Terrestrial radiation provides a major part of the potential energy changes necessary to drive the atmospheric wind system and is responsible for maintaining the surface air temperature within limits of livability.

Trace gas. [1] Any one of the less common gases found in the Earth's atmosphere. Nitrogen, oxygen, and argon make up more than 99 percent of the Earth's atmosphere. Other gases, such as carbon dioxide, water vapor, methane, oxides of nitrogen, ozone, and ammonia, are considered trace gases. Although relatively unimportant in terms of their absolute volume, they have significant effects on the Earth's weather and climate.

Transportation sector. [8] Consists of private and public passenger and freight transportation, as well as government transportation, including military operations.

Troposphere. [1&7] The lowest layer of the atmosphere and contains about 95 percent of the mass of air in the Earth's atmosphere. The troposphere extends from the Earth's surface up to about 10 to 15 kilometers. All weather processes take place in the troposphere. Ozone that is formed in the troposphere plays a significant role in both the greenhouse gas effect and urban smog. See *ozone precursor, stratosphere, atmosphere*.

Tropospheric ozone precursor. See *ozone precursor.*

Tropospheric ozone. [1] See o*zone*.

Ultraviolet radiation (UV). [11] A portion of the electromagnetic spectrum with wavelengths shorted than visible light. The sun produces UV, which is commonly split into three bands of decreasing wavelength. Shorter wavelength radiation has a greater potential to cause biological damage on living organisms. The longer wavelength ultraviolet band, UVA, is not absorbed by ozone in the atmosphere. UVB is mostly absorbed by ozone, although some reaches the Earth. The shortest wavelength band, UVC, is completely absorbed by ozone and normal oxygen in the atmosphere.

Unfinished oils. [3] All oils requiring further refinery processing, except those requiring only mechanical blending. Includes naphtha and lighter oils, kerosene and light gas oils, heavy gas oils, and residuum.

United Nations Framework Convention on Climate Change (UNFCCC). [1] The international treaty unveiled at the United Nations Conference on Environment and Development (UNCED) in June 1992. The UNFCCC commits signatory countries to stabilize anthropogenic (i.e. human-induced) greenhouse gas emissions to "levels that would prevent dangerous anthropogenic interference with the climate system". The UNFCCC also requires that all signatory parties develop and update national inventories of anthropogenic emissions of all greenhouse gases not otherwise controlled by the Montreal Protocol. Out of 155 countries that have ratified this accord, the United States was the first industrialized nation to do so.

Vehicle miles traveled (VMT).[8] One vehicle traveling the distance of one mile. Thus, total vehicle miles is the total mileage traveled by all vehicles.

Volatile organic compounds (VOCs). [6] Organic compounds that evaporate readily into the atmosphere at normal temperatures. VOCs contribute significantly to photochemical smog production and certain health problems. See *non-methane volatile organic compounds.*

Wastewater. [2] Water that has been used and contains dissolved or suspended waste materials. See *sewage treatment.*

Water vapor. [1] The most abundant greenhouse gas; it is the water present in the atmosphere in gaseous form. Water vapor is an important part of the natural greenhouse effect. While humans are not significantly increasing its concentration, it contributes to the enhanced greenhouse effect because the warming influence of greenhouse gases leads to a positive water vapor feedback. In addition to its role as a natural greenhouse gas, water vapor plays an important role in regulating the temperature of the planet because clouds form when excess water vapor in the atmosphere condenses to form ice and water droplets and precipitation.

Waxes. [2] Solid or semisolid materials derived from petroleum distillates or residues. Light-colored, more or less translucent crystalline masses, slightly greasy to the touch, consisting of a mixture of solid hydrocarbons in which the paraffin series predominates. Included are all marketable waxes, whether crude scale or fully refined. Used primarily as industrial coating for surface protection.

Weather. [1] Weather is the specific condition of the atmosphere at a particular place and time. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour-to-hour, day-to-day, and season-to-season. Climate is the average of weather over time and space. A simple way of remembering the difference is that climate is what you expect (e.g. cold winters) and 'weather' is what you get (e.g. a blizzard). See *climate.*

Wetland. [7] Land that stays flooded all or part of the year with fresh or salt water.

Wetlands. [2] Areas regularly saturated by surface or groundwater and subsequently characterized by a prevalence of vegetation adapted for life in saturated-soil conditions.

Wood energy. [2] Wood and wood products used as fuel, including roundwood (i.e., cordwood), limbwood, wood chips, bark, sawdust, forest residues, and charcoal.

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